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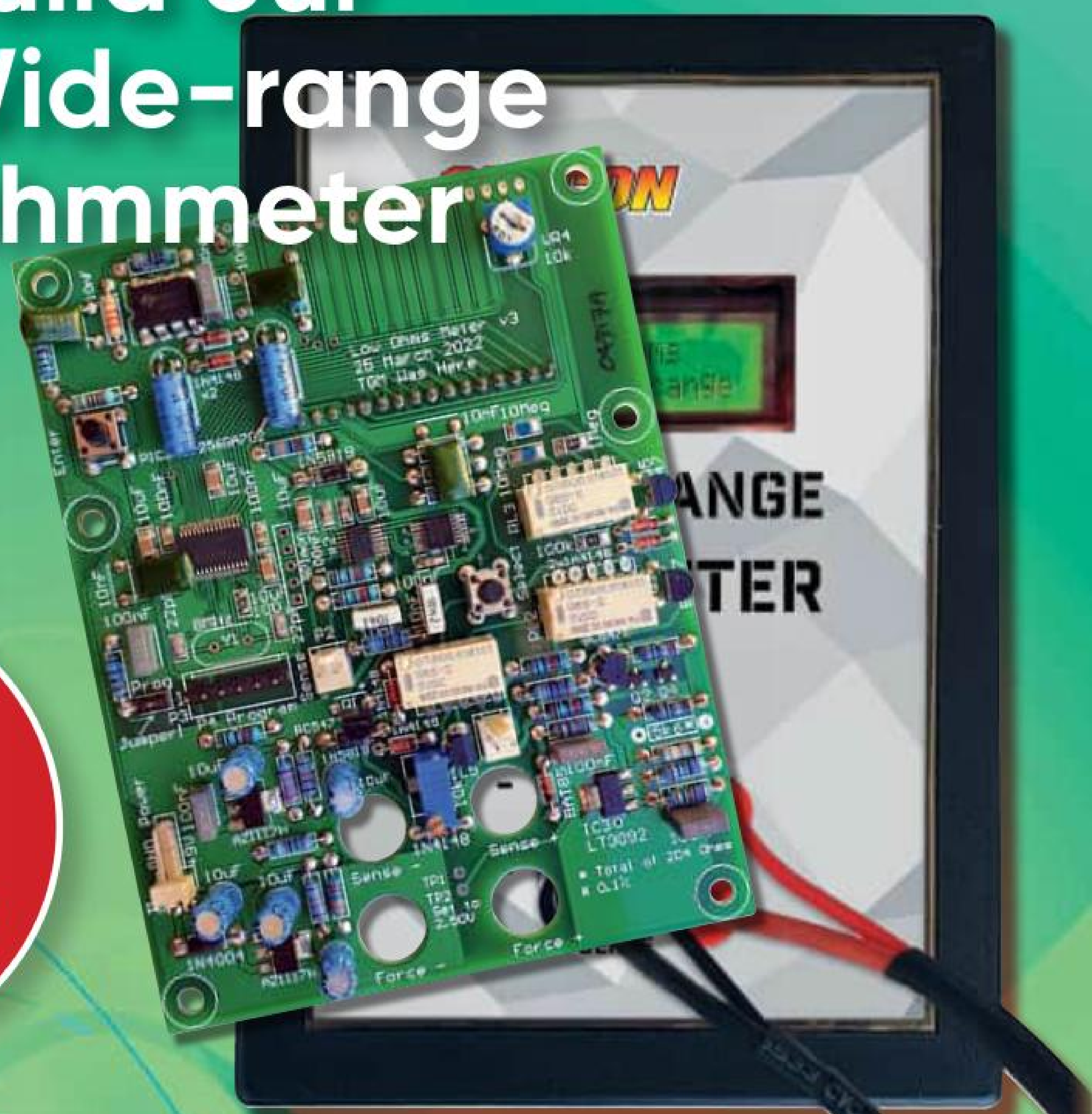

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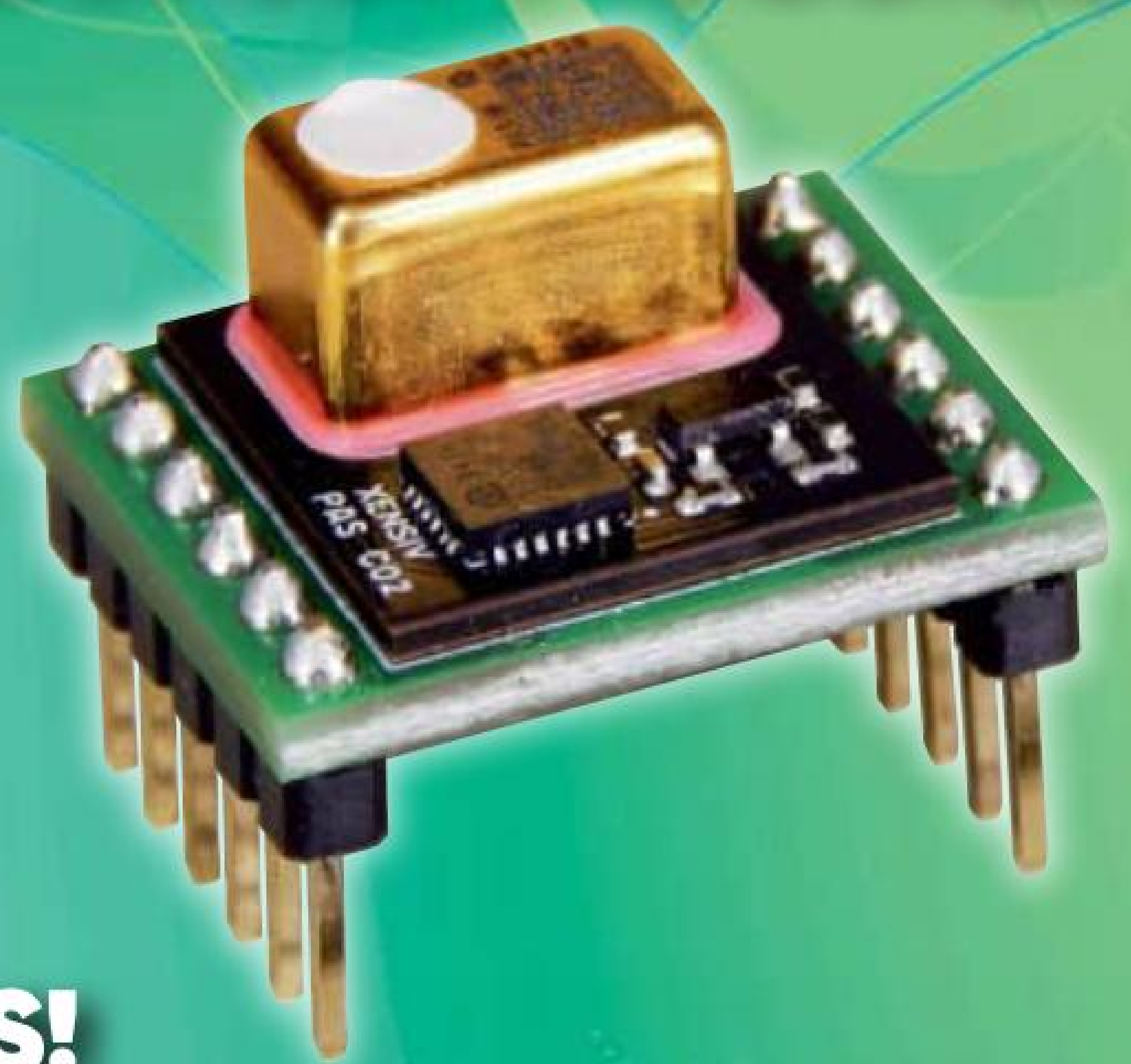

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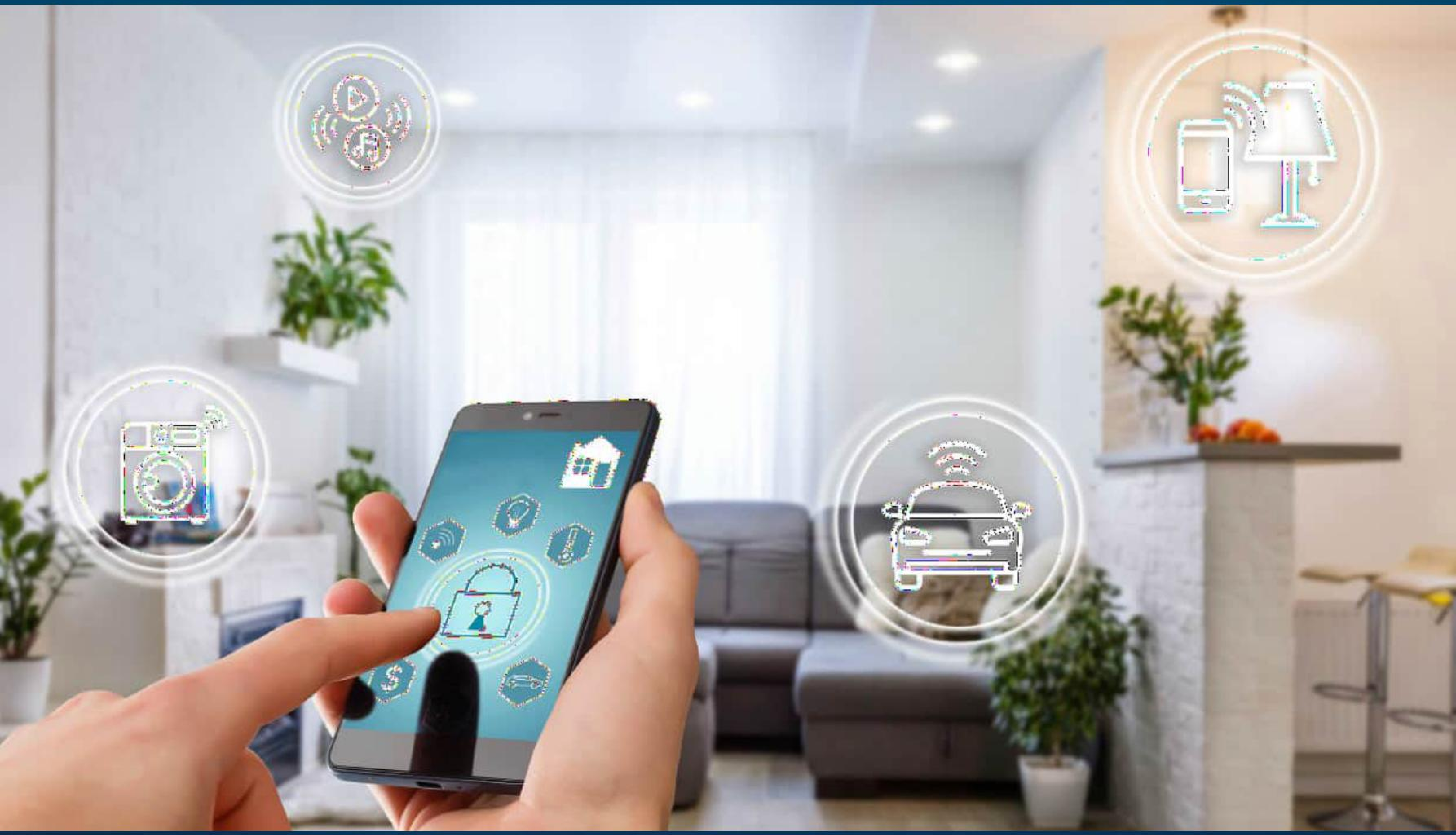

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ATTENUATOR

Made in the UK.

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Read everywhere.

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by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

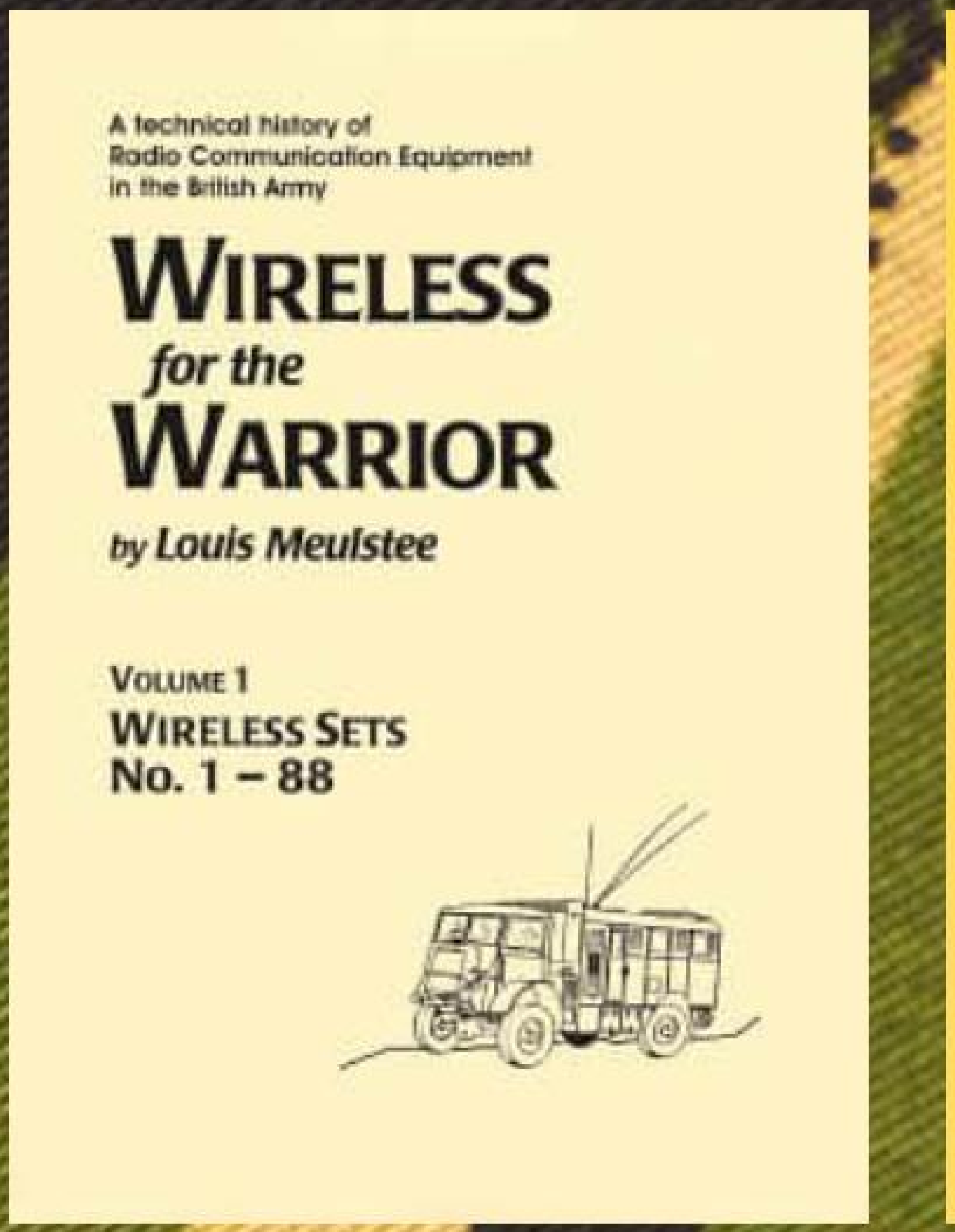
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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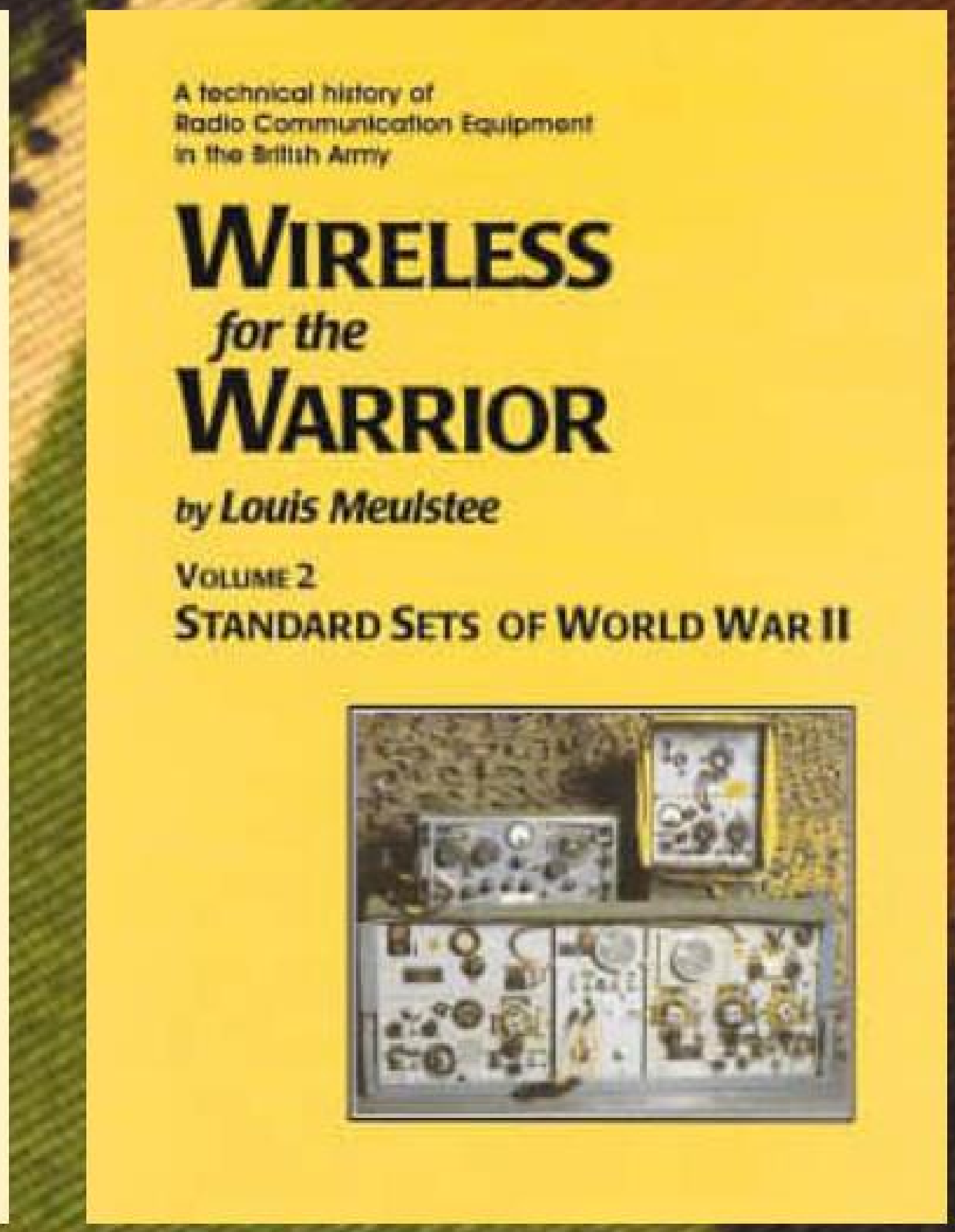

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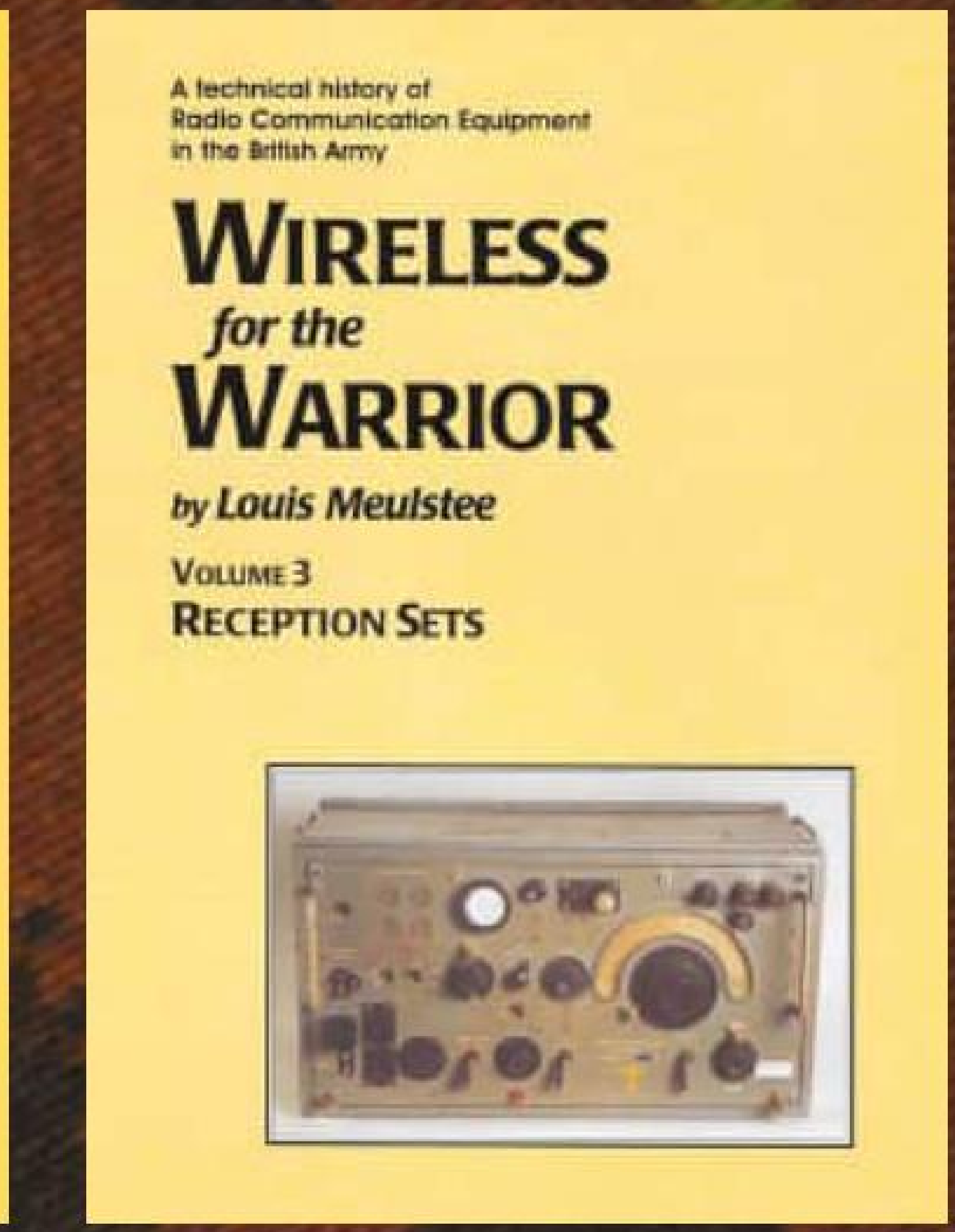

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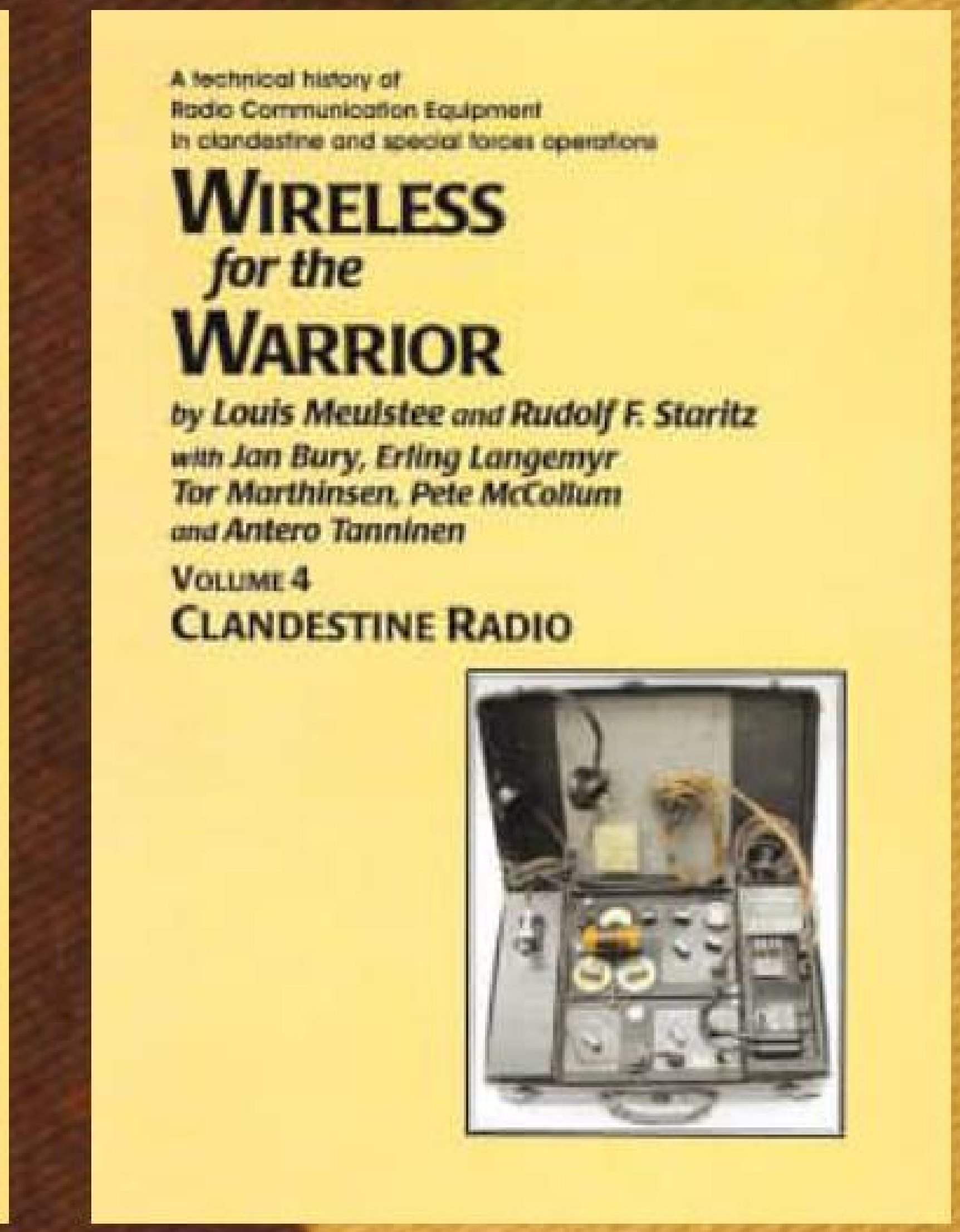

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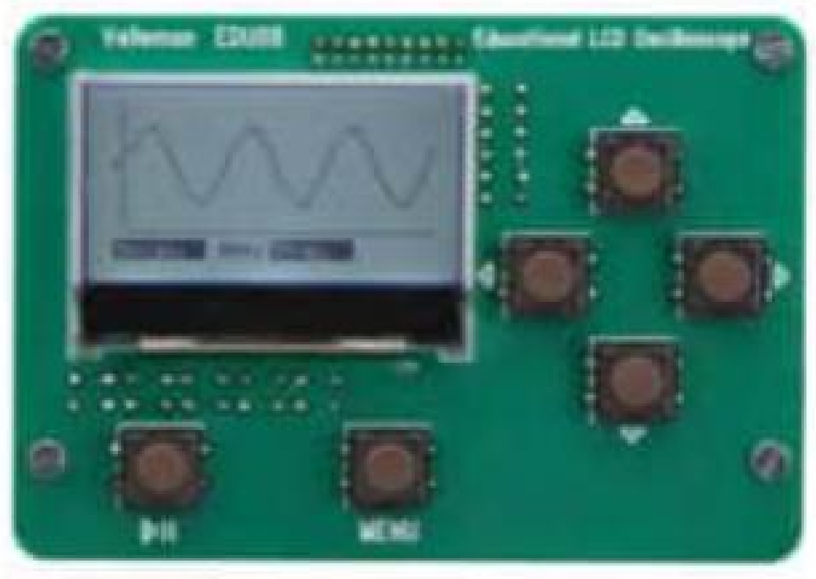

Build your own LCD oscilloscope with this exciting new kit. Learn how to read signals. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope kit has a lot of features found on expensive units like signal markers, frequency, dB, true RMS readouts and more. A powerful auto-setup function will get you going in a flash!
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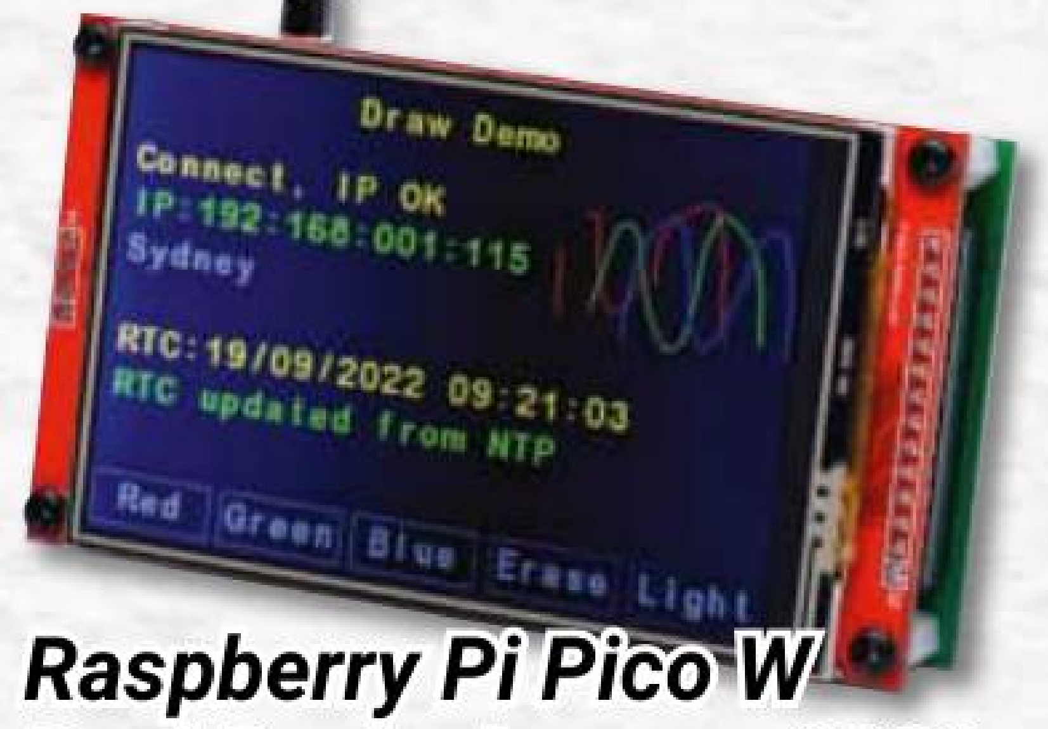
Draw Demo
Connect, IP OK
IP:192:168:001:115
Sydney
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RTC updated from NTP
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A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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Editorial

Interested in robots?

One project that really caught my eye this month is *SPY-DER*, an elegant design for a 3D-printed robot. It's a great example of how much has changed in the word of DIY robotics. What once was a real mechanical engineering challenge can now be easily tackled with an inexpensive 3D printer. All you need are a few simple-to-fabricate plastic parts and some low-cost servo motors, and pretty quickly you can be up and running with a fascinating dynamic system.

The other half of the robot equation is of course the controller, and here modern microcontrollers enable designers – new and experienced – to implement a huge variety of control systems of varying sophistication. *SPY-DER* uses representatives from both the Arduino and Raspberry Pi families of microcontrollers/single-board computers, neatly demonstrating how flexible control systems can be.

Wide-range OhmMeter

The other project I particularly enjoyed reading this month is our new *OhmMeter*. Measuring resistance, particularly very low values, is not an especially 'glamorous' topic in electronics, but there are times when you really do need to know the exact resistance value of a shunt or some other sub-ohm device. Ordinary DVMs are not much use here, and dedicated commercial instrumentation gets expensive very quickly. Our *Wide-range Ohmmeter* is the answer and really should be part of everyone's kit.

Need a (cheap) book?

We sell a few select books from our online shop; mainly as a service to our readers. These days it's not a great money-spinner, thanks of course to Amazon, and to a lesser extent eBay. They set the price against which all others compete and given the economies of scale they bring to the market, it can be very difficult to undercut them.

We recently had an order for *Newnes Electronics Toolkit* (2nd Ed, paperback) by Geoff Phillips. It's a good book, but it should be at £45! Unfortunately, we were out of stock, so I phoned the purchaser and offered a full refund. While we were chatting, I browsed eBay and Amazon and found plenty of secondhand copies from around £2.50. I suggested we provide one of these at cost since the contents would be the same and the book would be effectively 95% off the normal price. The purchaser agreed and I haven't heard any complaints. I mention this simply because a lot of electronics books have become very expensive, but if you don't mind a few dog-eared pages – sometimes not even that level of damage – then there are real bargains to be had online. An important point worth bearing in mind is that Amazon offers secondhand books, often from multiple professional vendors – do check them as well as auction sites. So, as Jake Rothman correctly points out in this month's *Audio Out* – it really is better to reuse rather than recycle (pulp!) a pre-owned book.

Matt Pulzer
Publisher

How long until we’re all out of work?

Techno Talk

Max the Magnificent

Generally speaking, I’m a glass-half-full type of guy, but some of the things I’ve been seeing recently have got me worrying. Could it be that, within the next decade or so, AI will be performing a lot of the things humans currently do, thereby leaving us all twiddling our thumbs?

These days, we are constantly being buffeted by a tsunami of information. In my case, I’m a sucker for the latest ‘Ooh, shiny’ nugget of knowledge or tidbit of trivia. The problem is that I’m easily distrac… ‘Squirrel!’ For example, here are a just couple of the notions that are bouncing around my noggin as I pen these words.

It’s life Jim, but…

Do you remember the episode in *Star Trek: The Original Series* when Spock said, ‘It’s life Jim, but not as we know it’? If so, you are like my mother, whose mind is so sharp she can remember things that haven’t even happened yet. As it happens, Spock never actually spoke these words. Similarly, Kirk never said, ‘We come in peace; shoot to kill.’ Both these quotes actually originated in the 1987 song *Star Trekkin’* by The Firm.

When I was a young lad, following our weekly boy scout meetings, my friend Jeremy (who lived just around the corner) and I would lay on the roof of his parents’ garage looking up at the stars wondering if alien boy scouts were looking back at us.

I personally am convinced that life in one form or another abounds in the universe. If you are wondering how life could spontaneously come into being, may I recommend *Life’s Ratchet: How Molecular Machines Extract Order from Chaos* by Peter Hoffmann. Also, *Wetware: A Computer in Every Living Cell* by Dennis Bray.

But what sort of life? Until a few years ago, if you’d asked me if there were other intelligent lifeforms in the universe, I would have responded, ‘Of course!’ That was until I read *Alone in the Universe: Why Our Planet Is Unique* by John Gribbin. Now I’m not so sure. On the other hand, more recently I also read *Imagined Life: A Speculative Scientific Journey among the Exoplanets in Search of Intelligent Aliens, Ice Creatures, and Supergravity Animals* by James Trefil and Michael Summers, which gave me cause for hope.

If you haven’t already seen it, there’s a brilliant 4-part series called *Alien Worlds* on Netflix. Depicted using awesome CGI techniques, this British sci-fi nature ‘docufiction’ blends fact with science fiction and conceptualises what alien life might be like by applying the laws of life on Earth to imagined exoplanets.

Did you know that, by mass, about 96% of our bodies are made of four key elements: carbon, hydrogen, nitrogen, oxygen? If we add in calcium, phosphorous, and sulfur, then we’ve covered 99% of what makes me (and you) so magnificent.

‘That’s very interesting, but what has any of this to do with technology,’ I hear you cry. Well, one of Saturn’s moons, Enceladus, boasts an enormous ocean of liquid water underneath an icy crust, plus it flaunts massive water geysers blasting various elements into space. The Cassini space probe (now, that’s technology) visited Enceladus about 15 years ago. Scientists are still rooting through all the data Cassini sent back. Just a few days ago, as I pen these words, they announced that they’ve detected phosphorus in these geysers, where this is the rarest of the six elements upon which life (as we know it, Jim) depends.

Brother, can you spare a dime?

The Great Depression, which consumed the decade from 1929 to 1939, was a devastating economic shock that ended up impacting most countries around the world. A mindboggling number of people ended up without jobs, money, homes to live in, and food to eat. (Written by lyricist Yip Harburg and composer Jay Gorney, *Brother, Can You Spare a Dime?* is one of the best-known American songs from that era.) If you don’t want to be depressed yourself, this might be a good time for you to stop reading this column and turn the page.

Did you hear the joke about the little boy who says to his father, ‘Dad, I’m an optimist because my glass of milk is half empty.’ The father responds, ‘You’ve got it wrong son, you’re only an optimist if you see the glass as being half full; you’re a pessimist if you see the glass as being half empty.’ The boy replies in turn, ‘It all depends on whether or not you like milk!’

I’m an optimistic glass-half-full type of guy. For some time, I’ve tended to the view that machine intelligence will be at its best when combined with human intelligence on the basis that both can perform tasks the other cannot. To put this another way, excluding the possibility of an artificial intelligence (AI) apocalypse with killer mechanoids hunting us down like… well, humans, I suppose, I have – until recently – been regarding AI in a positive light.

However, things are now speeding so fast on the AI front that I’m starting to worry. Many experts are predicting it won’t be long before AI reaches the level that it will be able to do almost anything humans can do, while doing it faster, better and cheaper.

Have you heard about Amazon’s Mechanical Turk workers? The idea is for businesses to outsource tasks to individuals, where these tasks – which take only a few seconds to do and pay only a few pennies for doing them – can only be done by humans (like solving a CAPTCHA) because AI isn’t capable of doing them. Jeff Bezos once quipped that this was ‘artificial artificial intelligence.’ Well, I just read a report (**https://bit.ly/446z7Pu**) that says around half these ‘turkers’ are now using AI to perform these tasks.

I’m currently reading *Homo Deus: A Brief History of Tomorrow* by Yuval Noah Harari. I just reached the part where Yuval informs us that two Oxford researchers, Carl Benedikt Frey and Michael Osborn, published a paper, *The Future of Employment*, in which they predict that, in the coming few years, there is an extremely high probability (as high as 99% in some cases) that people in certain professions will lose their jobs to AI algorithms. We are talking about all sorts of jobs here, from paralegal assistants to bus drivers to construction workers to… Ah, technology, what can you say, eh?

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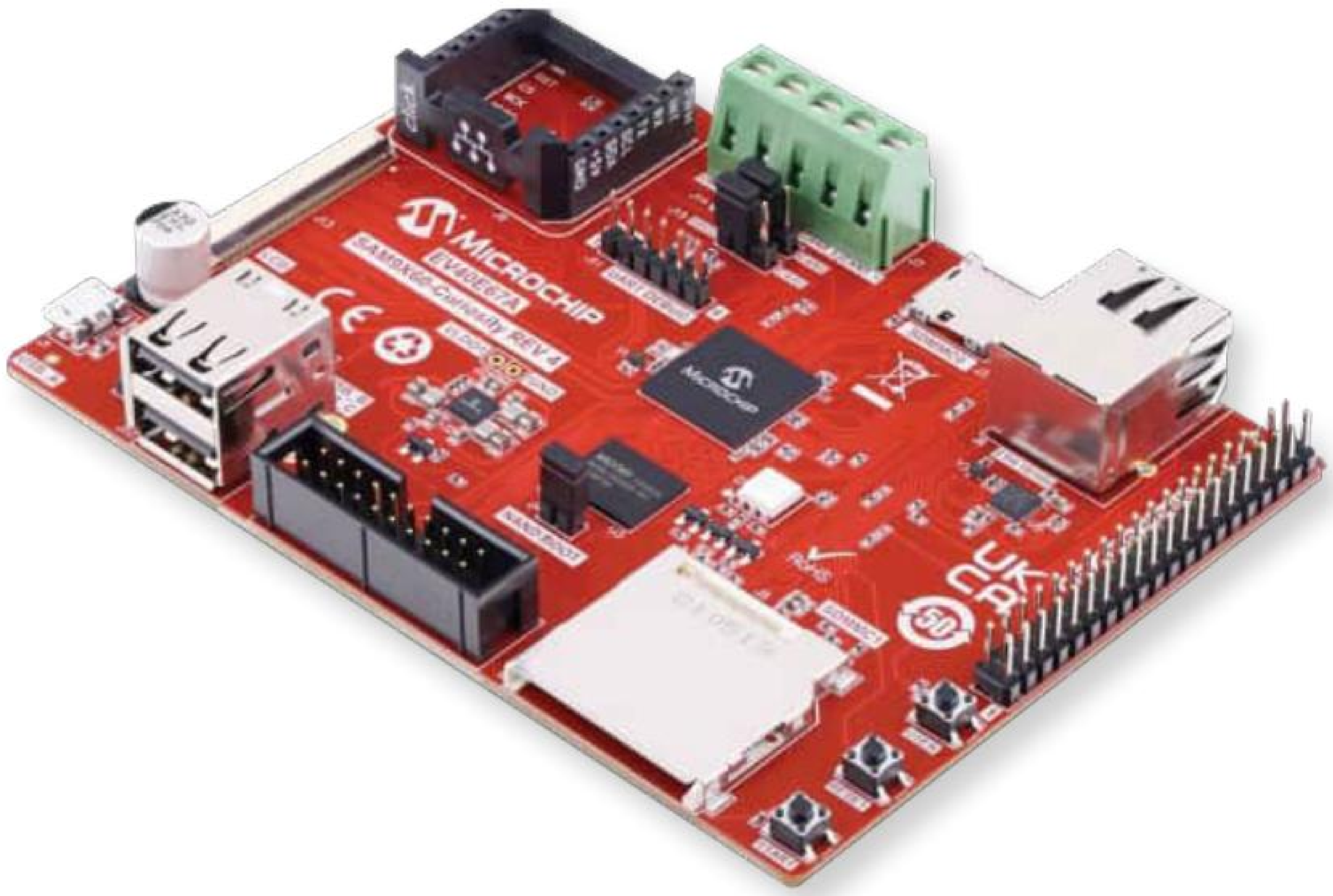

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The **Fox** Report

Barry Fox's technology column

Online purchase pitfalls and parrot loops

Online trading – for sellers and buyers – is now for most of us a routine way of life. Covid, of course, accelerated the movement away from the High Street and on to the Internet. On a macro scale, it does work amazingly well. From daily groceries to high-priced white goods and computers it is a great way to compare prices and make purchases. But, as this piece shows, when things go wrong the virtual High Street can be a very lonely place, with industrial levels of buck passing, evasion and obfuscation.

Failed to arrive

I buy large and small electronics direct from dealers and via Amazon and eBay (at fixed price, not by auction). Delivery is variously by mail and courier. My recent experience with an eBay purchase, shipped via Royal Mail, has left me cautious of ever again relying on the eBay/Royal Mail combination.

Few customers will have the time (and be foolish enough) to spend as much effort as I am on investigating the loss of a £50 package. So, a synopsis may be worth sharing.

My purchased goods failed to arrive, so I queried with eBay. The seller claimed despatch and provided eBay with Tracking Data provided by Royal Mail, which purported to show that the package was delivered and signed for.

But Royal Mail's 'Proof of Delivery' relied on clearly phoney data. The data does not give the address for delivery given by the seller; does not give the address of actual delivery; does not provide photographic evidence of delivery and, most significantly, contradictorily claims that the item was signed for by 'Jerry' but reproduces a signature scribble which looks like 'snc'. There is no one at my address (or among my neighbours) who signed for anything, and no one has any name or signature remotely resembling Jerry or 'snc'.

Pass the parcel

Over the course of well over a dozen emails, I have repeatedly explained this to eBay and eBay has repeatedly instructed me to contact Royal Mail, asking Royal Mail to admit non-delivery. Royal Mail repeatedly refuses to admit non-delivery or acknowledge or investigate the phoniness of its Tracking Data. eBay still steadfastly refuses a refund unless Royal Mail admits failure to deliver.

It's a parrot loop impasse, made doubly difficult, frustrating, time-consuming and Kafkaesque because eBay's emails are sent from a no-reply address and refer to a Help page (**https://www.ebay.co.uk/help/home**) which is of little help and takes the frustrated user round in circles. The only way to reply to eBay is by filing a fresh complaint referencing the previous complaint. But the new message has a rigid 1000 character limit and uploaded evidence must be as a pdf or image file (gif, .jpg, .jpeg, .pdf, and .png). Each filing is dealt with by a different employee.

The latest different eBay employee confirms 'I acknowledge your assertion that the Royal Mail Tracking document does not provide sufficient evidence of delivery, especially considering the discrepancies in signatures and the lack of address records or photographic evidence.' But eBay then just parrots its insistence on 'confirmation from Royal Mail, stating that the item has not been delivered to your address' – which the Royal Mail parrots refuse to provide!

Breaking the loop

As an experiment, I have now started exploring other ways to break out of the eBay/Royal Mail parrot loop. Perhaps, fortunately my eBay account is tied to my credit card, so I have now sought help from the credit card company in obtaining a refund from eBay, on the grounds that eBay was in error to rely on obviously phoney Royal Mail Tracking data.

I have also filed a crime report with the police, detailing Royal Mail's failure to recognise or investigate self-evident fraud in its Tracking Data.

I will share the outcomes, good or bad; and also from other remedy avenues yet to be explored. Watch this space!

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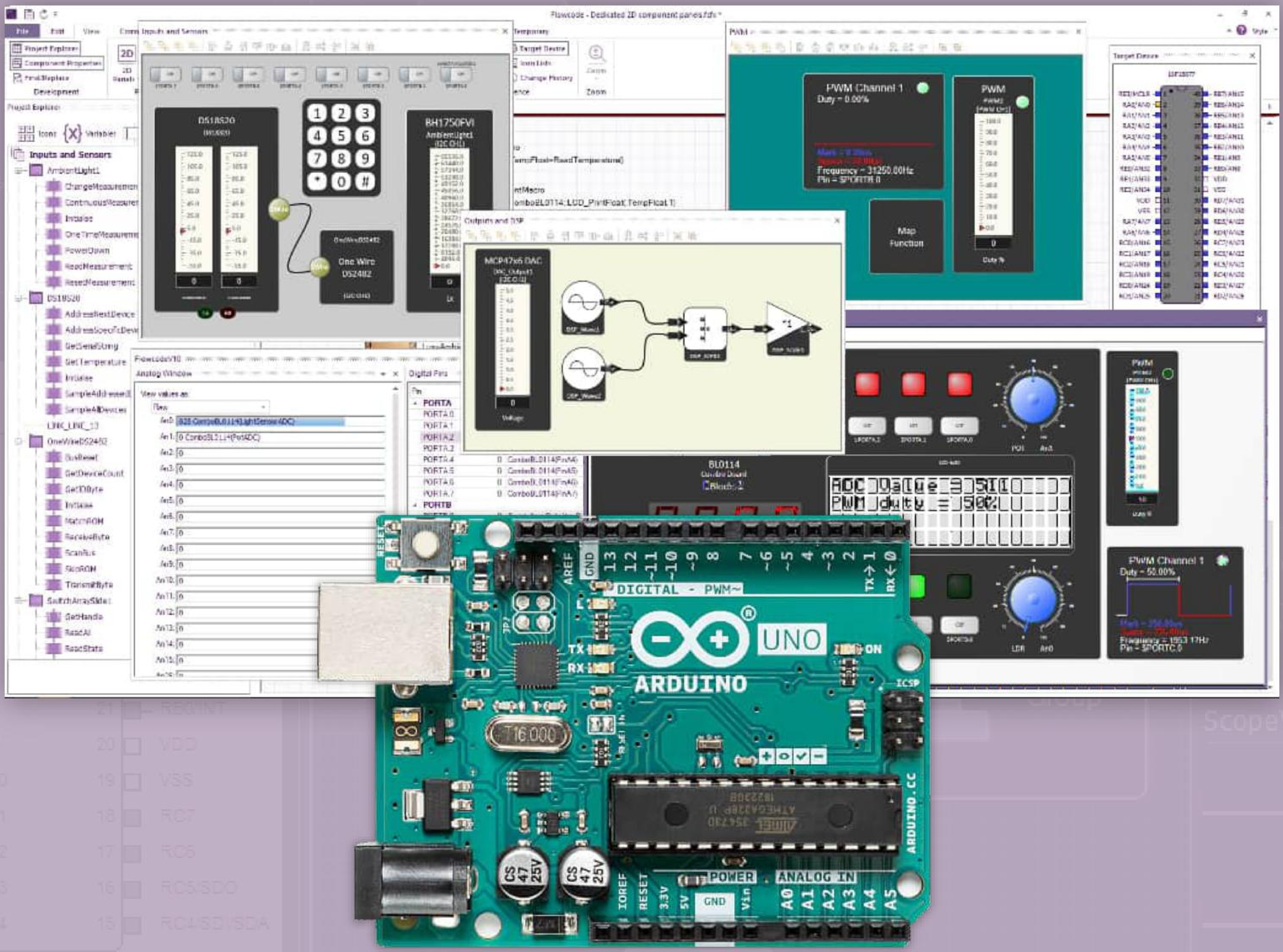
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Net Work

Alan Winstanley

Our Net Work columnist observes how Chinese EV makers are queuing up to conquer Europe, AI is becoming ever more humanlike and there's news of NASA's ambitions to return soil samples from Mars.

Recently an old, abandoned shipping container holding three Tesla Roadster cars made 13 years ago, was found at a Chinese quayside. The Teslas were reportedly destined for a start-up EV maker to be dismantled and their technology copied, but the EV maker had gone bust and the cars, worth $2m today, were being auctioned off. China's nascent car makers have seized every opportunity to get a toehold in the global car market, having started by grabbing some well-known brand names. The famous British marque Rover became 'Roewe' under Chinese ownership and, as a sign of how rapidly its owners Shanghai Motor (SAIC) have evolved since then, their range now covers everything from a tiny all-electric car (the Roewe Clever), up to some monstrous-looking SUVs, such as the RX-9: **https://bit.ly/pe-aug23-ro1**

Their website showcases a wealth of vehicle design and production that is seemingly limitless. You can take a virtual tour of these brittle-looking cars online, and the Google Lens app on a smartphone is great for translating Chinese web text into English – see: **https://bit.ly/pe-aug23-ro2**

Until the 1980s, car ownership in China was unthinkable: according to the *Christian Science Monitor*, in 1985 the average was one passenger car per six million people. In December 2020's *Net Work* I wrote how Chinese-owned SAIC had grabbed the British MG brand to market its own Chinese-built cars, describing themselves as a '94-year-old start-up'. As predicted, thanks to their keenly priced EVs, the MG brand has enjoyed stellar growth, both in Britain and overseas. Fast forward 2½ years to today and, according to SMMT statistics, MG has sold in 2023 about 32,000 units, or 4.1% of the UK car market share, 2½ times more than Renault (13,000), with volumes approaching those of mainstream Vauxhall cars (39,000). Tesla sold 18,600 cars, after disrupting the market with major price cuts.

Despite the decline of British car brands, we can still claim that Britain's MG saloons contained the first mainstream digital dashboard nearly 40 years ago, see: **https://youtu.be/gH8orI8jdCA** – preceded only by the dire and best forgotten electronic dash on the 1976 Aston Martin Lagonda, a favourite of oil sheiks at the time.

The luxury HiPhi X has TI (Texas Instruments) micromirror-controlled headlights and on-road night-time warnings.

HiPhi's sophisticated dashboard is dominated entirely by three HD screens for managing the car's controls.

Hi Phives

There's more to come: back in April, UK Government officials met in Shanghai

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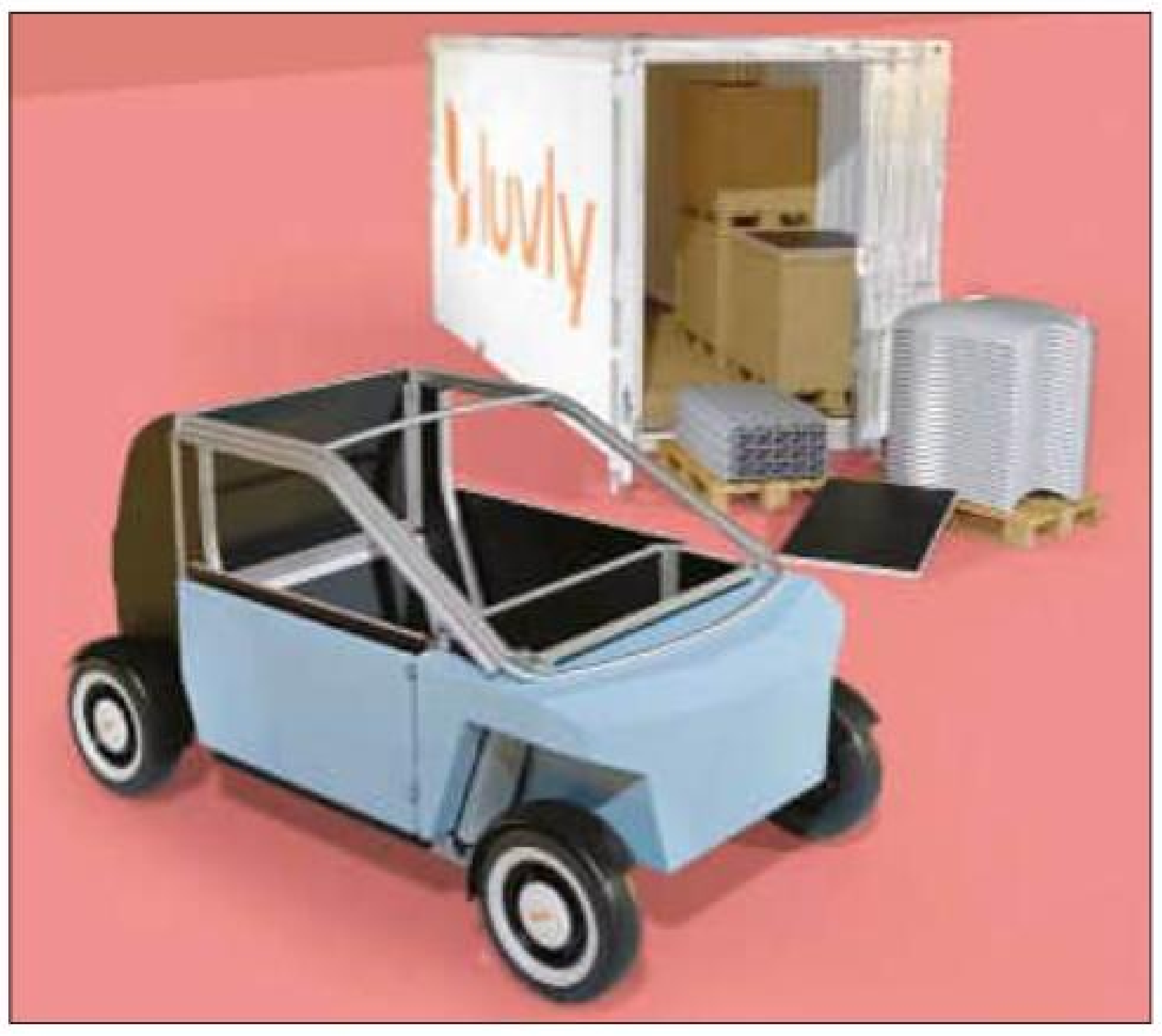


A tiny electric Light Utility Vehicle (LUV) has been proposed by Sweden's Luvly AB. It would be assembled from kits in microfactories.

with the CEO of Chinese luxury car maker HiPhi, a brand owned by Chinese group Human Horizons that I mentioned briefly in June's issue. HiPhi has ambitions to sell their ultra-sophisticated high-end electric cars in Europe, and they 'expressed hope to see HiPhi cars on the UK streets soon'. Tomorrow's technology is heading our way and these premium cars show what's now possible today. The cars are crammed with tech, including LED matrix headlights directed by 2.6 million individually-controlled Texas Instruments digital micromirror devices (DMDs – see: **https://bit.ly/pe-aug23-ti**), electronic technology that shapes the beam and makes today's car headlights seem like acetylene-burning carbide lamps in comparison.

From what I can gather, their 'night-vision imaging' LED lights project warning signs onto the road surface, with features like 'intelligent pedestrian tracking', which detect bystanders waiting to cross. Naturally, the dash is dominated by digital screens and the feature list is out of this world. Under the heading of 'Too silly', though, must come the idea that its LED matrix lamps can download and display text, emojis and animations. Whether it complies with UK road regulations is doubtful; an early taster is at: **https://youtu.be/mAkIXVnH7sU** and you can sign up for news or see more about the HiPhi-X at: **www.hiphi.com/hiphi-x**

This inexorable shift towards electric propulsion is creating a sea-change in the auto market, hampered in Britain by the usual infrastructure problems and bottlenecks. BYD (Build Your Dreams, see *Net Work*, May 2023) has shifted just 84 of their electric Atto 3 SUVs so far, according to SMMT figures. But this EV builder is huge in Asia and has big plans to conquer Europe with their next cars, called the Dolphin and the Seal. The GWM (Great Wall Motor) Ora 'Funky Cat' described 18 months ago (see *Net Work*, January 2022) has sold just 258 so far this year, but Ora has already set its sights on expansion, with a so-far unnamed premium saloon coming in 2024. Some teaser shots are at: **https://gwmora.co.uk/nextgwmora/**

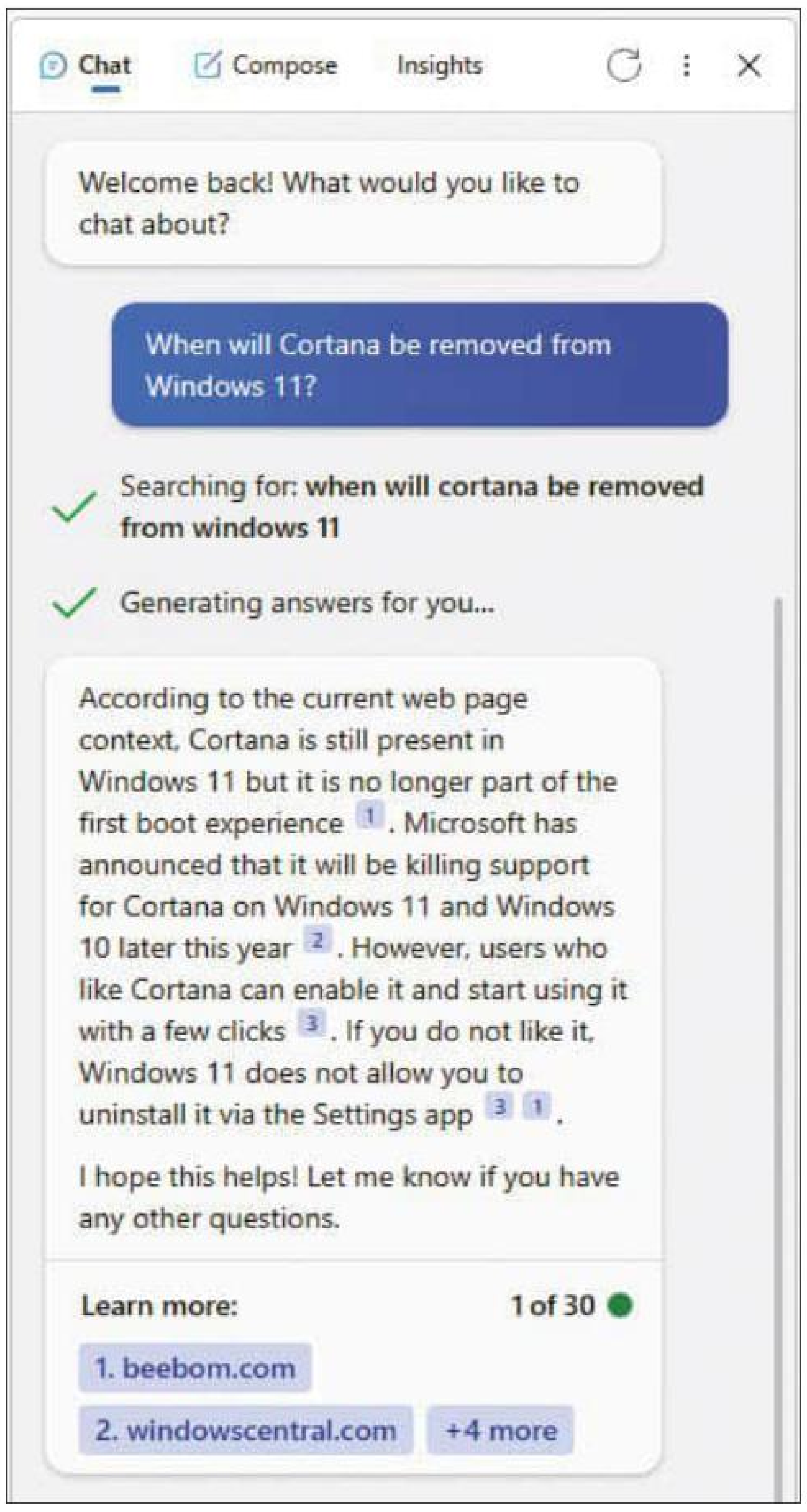
Dealer appeal

New brands like BYD and Ora are slowly and carefully building up a dealership network and, judging by MG's success, they are in it for the long term. Here in the UK, it feels like owners of fossil-fuelled cars are becoming an endangered species, with all manner of 'green' policies making car ownership difficult and increasingly unrewarding; yet EVs are still expensive and, for many, remain impractical to use.

Prices of used EVs are finally starting to recover, says *Autocar*, yet 29 of the top 30 biggest used car price drops in the last six months were still electric vehicles, according to the trade site *Car Dealer*. Cars are being seen more as 'white goods', Heycar's CEO Karen Hilton is quoted as saying: brand loyalty in Britain is fast disappearing and cars are now being purchased simply because customers 'need one', showing little regard to the badge on the hood. This trend will be manna from heaven for Chinese car makers trying to expand into the market.

The Internet has played a major role in skewing the way cars are bought and sold. Instead of trawling round showrooms and grabbing brochures, websites such as Heycar, Cinch and Cazoo have sprung up selling cars online, all polished up nicely to look like new. Personally, I find it incredible that consumers would buy an expensive car at arm's length without trying it first, reassured only by a money-back guarantee – but some people really do. This idea backfired on Cazoo, who over-expanded into Europe and has since shut down all its overseas sales operations. However, not even Rolls-Royce produces a printed brochure now, but when I played with their 'online configurator' I was greeted with a 'Something went wrong' pop-up that redirected me to a '2D Experience' instead. Even Rolls-Royce gets online sales wrong sometimes.

At the other end of the scale, another emerging segment is the 'NEV' or Neighbourhood Electric Vehicle, tiny electric cars and mini-trucks capable of no more than 25 mph for zipping round town, though these have yet to appear in Britain (where new urban 20mph speed limits and punitive emissions charges are proving highly unpopular). The Ed and I were just joking about how a flat-pack car would be good for use around town, when news arrived of a concept EV that is just that – a brilliant idea from Sweden (where else?). The 'Luvly O', which is the brainchild of Luvly AB, is classed as an 'LUV' or light utility vehicle. Designed from the start to be lightweight but tough and safe, the tiny, spartan two-seater has urban life firmly in mind and would be ideal for nipping around congested towns. The Luvly O aims to be



Welcome back! What would you like to chat about?

When will Cortana be removed from Windows 11?

✓ Searching for: **when will cortana be removed from windows 11**

✓ Generating answers for you...

According to the current web page context, Cortana is still present in Windows 11 but it is no longer part of the first boot experience [1]. Microsoft has announced that it will be killing support for Cortana on Windows 11 and Windows 10 later this year [2]. However, users who like Cortana can enable it and start using it with a few clicks [3]. If you do not like it, Windows 11 does not allow you to uninstall it via the Settings app [3] [1].

I hope this helps! Let me know if you have any other questions.

Learn more: 1 of 30 ●

1. beebom.com
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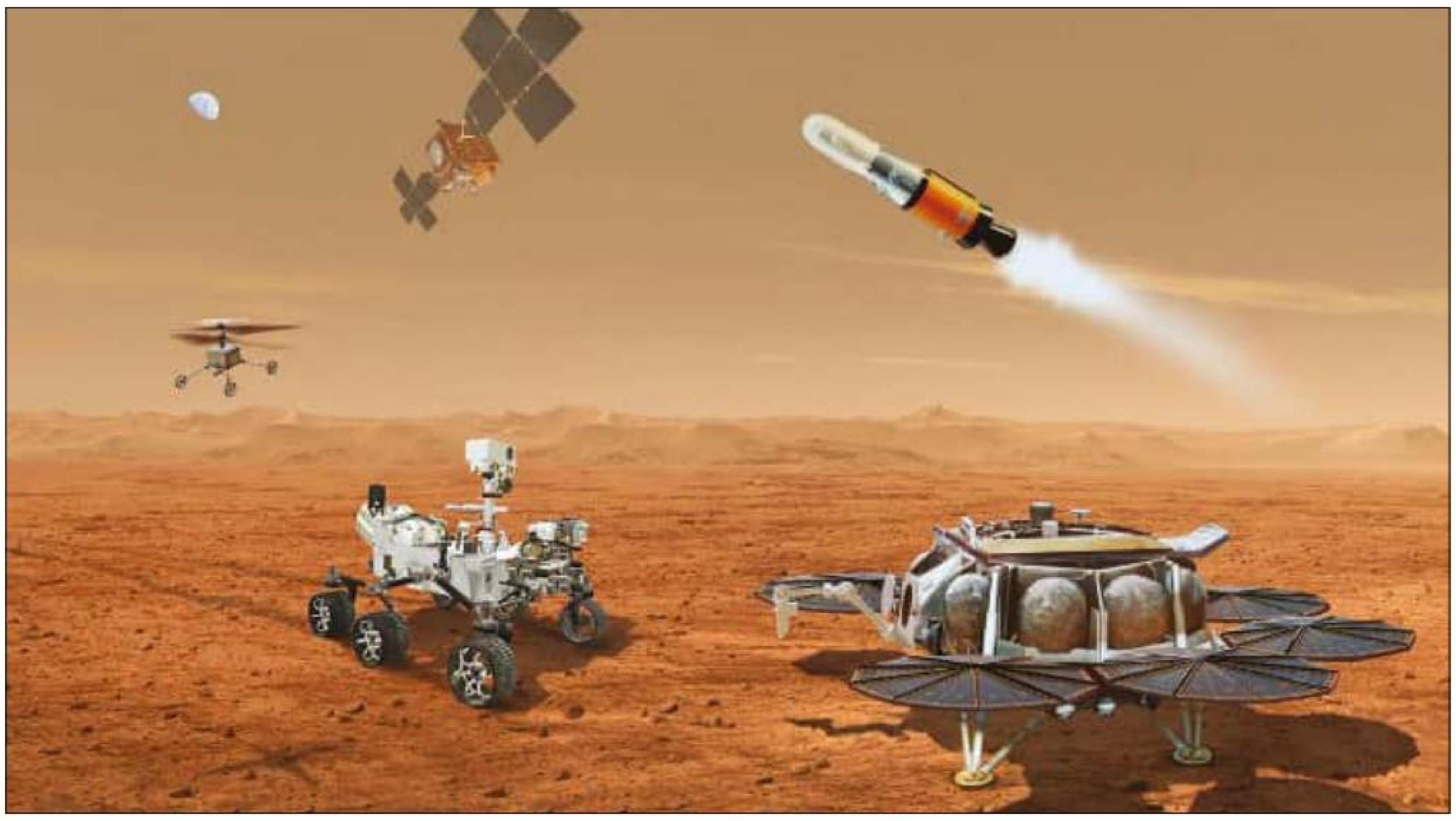
Bing Chat is a conversational system integrated with Microsoft's search engine that allows users to talk to its AI chatbot rather than simply filling out search queries. (Bing Chat's own definition of itself.)

sustainable and fully recyclable and uses just two small batteries giving a range of 60+ miles. Naturally, it would communicate with a Luvly app on the driver's smartphone. Unlike Chinese NEVs, the Luvly O could indeed be delivered as flat packs, IKEA style, although not to the end-user (no confusing instructions to deal with, then!), but in kit form to regional microfactories for local assembly. The vehicle – if it ever sees production – is a few years away yet and would cost about €10,000 (£8,600). You can sign up for newsletters and find more details at: **www.luvly.se**

Artificial sweeteners

Artificial intelligence (AI) is never far from the news and there's no escaping the impact that AI now has on mundane everyday activities. There aren't enough expensive human beings (or phone lines) to offer us a personal customer service anymore, so many of us have been conditioned into using online 'chat' instead. Terminal-style chat may be awkward and robotic but there might at least be a human being at the other end, maybe halfway round the world or working from home in a bedroom somewhere. Humanoid chatbots are increasingly relying on AI to try holding intelligent conversations with us, and a lot of AI-crafted content is now indistinguishable from human-generated material. The paradox is that, in trying to emulate a human response, AI-powered chat seems to de-humanise the experience even more.



The Mars Sample Return Mission (MSR) would see samples of Martian rocks and sediment return to Earth for analysis, ten years from now. (Image: NASA/JPL-Caltech)

The advent of ChatGPT – an OpenAI chatbot programmed to converse naturally – has caught the public's imagination and has been covered extensively by others. You can try it at: **https://chat.openai.com** – note that the site openly admits that it may sometimes generate wrong information and harmful or biased content. Intelligent chatbots do have their uses though, and when they work efficiently, they can save time and hassle – for example, when I used their own chatbot to close an OpenAI account.

Elsewhere, Microsoft is finally killing off Cortana, its unloved and largely forgotten voice assistant. Having already abandoned mobile applications, Cortana as a standalone app will silently disappear from Windows 10 and 11 towards the end of this year, a measure Microsoft quietly announced in an earlier bulletin, see: **https://tinyurl.com/mr323r4e**

In its place, new AI-powered search technology is being used that gives Bing search results an altogether friendlier, chatty style. I must admit that using Bing's AI in Microsoft Edge to search the web makes a pleasant change from punching in search phrases and trawling mindlessly through pages of hyperlinks and paid-for ads.

Waiting in the wings is Windows Copilot, a centralised AI tool coming to Windows 11 that promises to 'help people easily take action and get things done'. Bing and ChatGPT plugins will be embedded into the Windows OS, and Windows Copilot promises (at last) to offer plain English AI-generated answers to our everyday questions, acting like a more intelligent Help screen. Copilot is already making its way into Microsoft Office 365.

Is there life on Mars?

Back in *Net Work*, October 2020, I wrote that NASA had launched a space mission to Mars hoping to fly a small helicopter called Ingenuity in the very thin Martian atmosphere, which has just 1% of the Earth's density. This feat would be the first such powered flight made on another planet. The helicopter's mothership, called Perseverance, is a mobile laboratory bristling with sophisticated geological test equipment and it landed successfully on Mars in February 2021. Ingenuity was then released to fly ahead as a 'scout' for Perseverance. Although Ingenuity was expected to fly just five missions as a proof-of-concept demonstrator, the hovering craft has exceeded all expectations and has now celebrated more than 50 successful flights, travelling a total of nearly 12km. NASA engineers have learned how to exploit gruelling weather patterns, for example, to let frozen components thaw out in the sun again, after the helicopter has taken a nap in hibernation mode. The fascinating story of some of Ingenuity's perilous journeys is recounted by NASA engineers at: **https://bit.ly/pe-aug23-nasa**

Looking to the future, an even greater challenge is that of returning Martian soil samples to Earth, and for this NASA has partnered with ESA, the European Space Agency, as part of the highly ambitious Mars Sample Return (MSR) project. The scale of the technology needed is astonishing: samples of Martian rocks and sedimentary deposits, contained in small tubes, would be gathered together at a location on Mars

GALACTIC
VMS EVE
VSS UNITY

Virgin Galactic's twin-bodied space carrier plane VMS Eve releases the VMS Unity space plane on a successful test flight prior to going commercial. (Image: Virgin Galactic)

and a craft called the Sample Return Lander would eventually land with extreme precision nearby. The lander would contain a small rocket – the two-stage Mars Ascent Vehicle (MAV) – into which the sample tubes would be loaded by a Perseverance-type rover, helped by two Sample Recovery Helicopters. Ten such soil sample tubes have already been curated by Perseverance, patiently awaiting their collection some time in the distant future.

In another space programme first, the MAV rocket would then be launched from Mars back into orbit, to rendezvous with an Earth Return Orbiter (ERO) launched separately from Earth by the European Space Agency. It would be the first interplanetary spacecraft to capture an object orbiting around another planet and make a full round trip to Mars and back again. For this to happen, NASA's Capture, Containment, and Return System (CCRS) would 'capture the Martian sample container in orbit, double-seal it in a clean vessel, and integrate it into the Earth Entry System, which would safely return the samples to Earth's surface', NASA says. The feasibility of this highly ambitious programme will be scrutinised by an independent review board this year. If it goes ahead, a target of the early 2030s has been slated for the MAV launching from the red planet, carrying its priceless Martian booty back to Earth. I hope a future *Net Work* writer will be able to report on its success, but in the meantime you can learn more at: **https://mars.nasa.gov/msr**

Galaxy Invader

In other space news: sadly, Virgin Orbit's efforts to re-finance its 747-based LEO launcher were unsuccessful, leaving the bankrupt company with no choice but to break up and sell off the company's assets – proof that space is still hard to do. There is better news from Virgin Galactic's space tourism programme, though (*Net Work*, July 2021), as the company has successfully completed a spaceflight of its twin-bodied carrier plane 'mothership', the VMS Eve, in readiness for the company's first commercial flight. After being transported into the upper atmosphere by the plane, the re-usable orbital spaceplane will reach an altitude of 80km, carrying its passengers and crew. The craft then folds in two,

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Under construction: Sierra Space's Dream Chaser is the world's only winged commercial spaceplane, set to supply their privately owned Orbital Reef space station.

offering passengers a glimpse of space and the planet below, before gliding back to earth.

Meanwhile, US manufacturer Sierra Space is a commercial space company currently constructing what will be the world's only winged commercial spaceplane, the 'Dream Chaser'. The craft is intended to resupply the International Space Station, and would land back on Earth on 'compatible airport runways'. (Fun fact: NASA's original 1980s Space Shuttle missions would land back on airstrips either in Florida or California, but one back-up emergency landing site was none other than Doncaster Sheffield airport in England, which had one of the longest runways in the country. My parents were married in Finningley church, by the same RAF runway.)

The first Dream Chaser space plane was successfully powered up for the first time at the end of May. Sierra Space is also building the backronym-titled LIFE habitat (Large Integrated Flexible Environment), described as a 'modular, three-storey commercial habitation and science platform designed for low-earth orbit'. The Dream Chaser spaceplane and the LIFE platform are key elements in their proposed 'Orbital Reef' space station, the first commercially owned and operated private space station, described as a 'mixed-use business park in low-earth orbit', being developed by Sierra Space and Blue Origin, the space corporation owned by Jeff Bezos. It is slated to be operational by 2027. As they say, remote working will never be the same again, and you can learn more about the Orbital Reef at: **www.sierraspace.com**

Amazon Kuiper's smallest and lowest-cost satellite Internet terminal will measure just seven inches square.

Finally, this month, on the LEO broadband front, in a market dominated by SpaceX's Starlink service, Amazon's long-overdue Kuiper program has finally received the green light from the US Federal Trade Commission. The service, first mentioned four years ago in *Net Work*, will eventually see a constellation of some 3,200 LEO satellites launched in 77 missions, to beam Internet services back down to earth. It will harness Amazon Web Services (AWS), their managed cloud-computing platform, which is used by everyone from small operators all the way up to the UK Government. Amazon expects to start building five satellites a day in its own facility and is compelled to have at least half of the satellite constellation operational by July 2026. The aim is to start connecting early adopters by the end of 2024 and a range of terminals will be offered. The fastest service is expected to offer a speed of 1Gbps for high-bandwidth users, but a small 7-inch array may suit home users or travellers.

That's all for this month's *Net Work* – you'll find all the above links ready-made for you in the *Net Work* blog on the *PE* website at: **www.electronpublishing.com**

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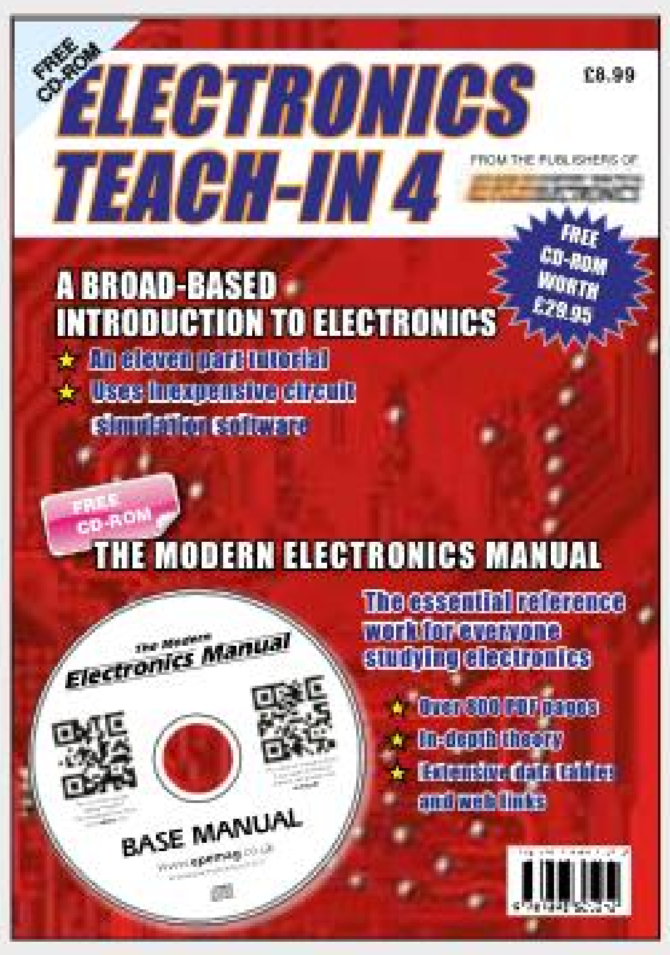
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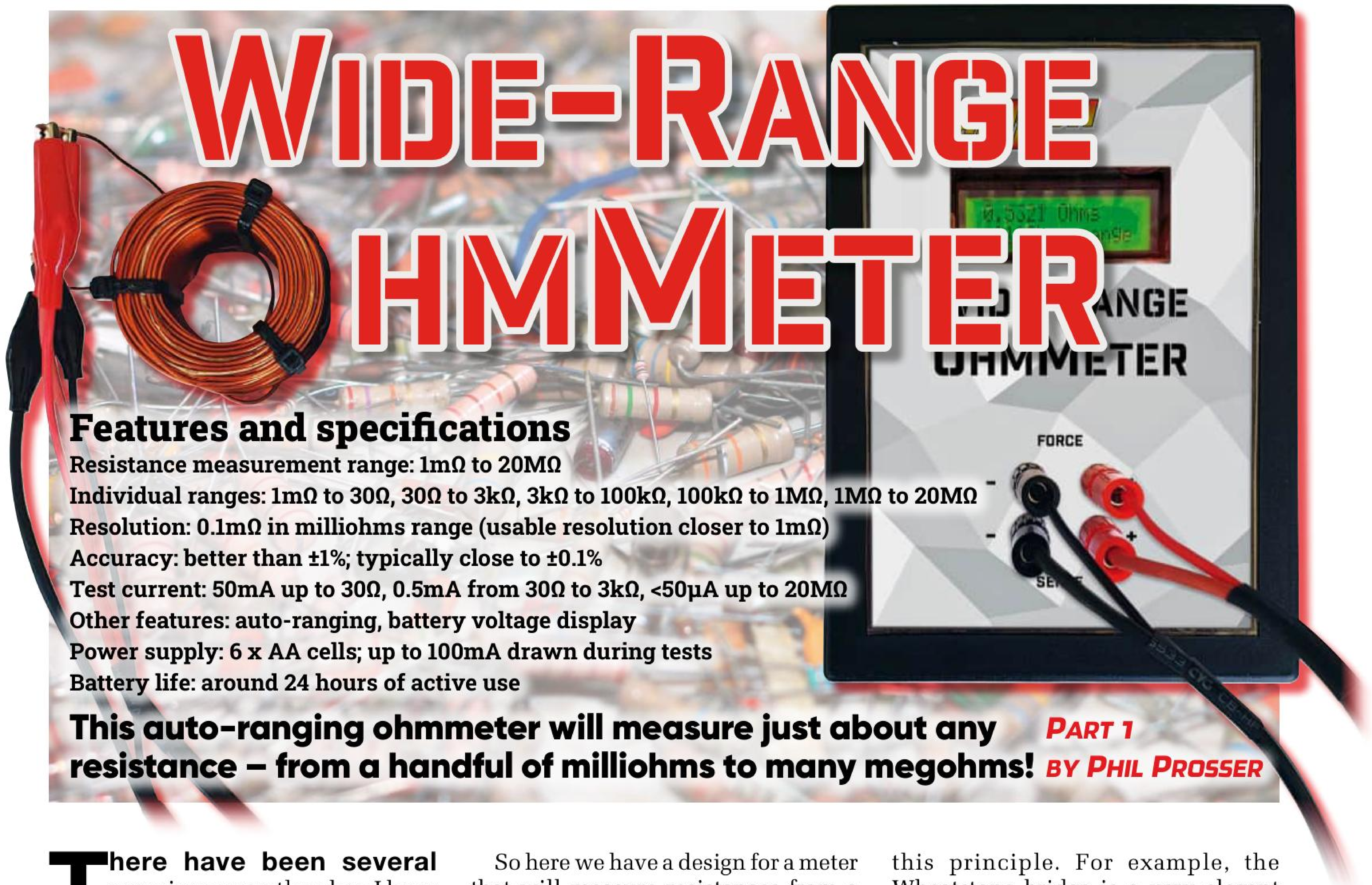


Wide-Range OhmMeter

Features and specifications

Resistance measurement range: 1mΩ to 20MΩ
Individual ranges: 1mΩ to 30Ω, 30Ω to 3kΩ, 3kΩ to 100kΩ, 100kΩ to 1MΩ, 1MΩ to 20MΩ
Resolution: 0.1mΩ in milliohms range (usable resolution closer to 1mΩ)
Accuracy: better than ±1%; typically close to ±0.1%
Test current: 50mA up to 30Ω, 0.5mA from 30Ω to 3kΩ, <50µA up to 20MΩ
Other features: auto-ranging, battery voltage display
Power supply: 6 x AA cells; up to 100mA drawn during tests
Battery life: around 24 hours of active use

This auto-ranging ohmmeter will measure just about any resistance – from a handful of milliohms to many megohms!

Part 1

by Phil Prosser

There have been several occasions recently when I have needed to measure low resistances accurately. That includes some speaker projects, where I needed to accurately determine the DC resistance of a voice coil to estimate a driver's Thiele-Small parameters or find the resistance of an air-cored power inductor.

Another time it was for the *Capacitor Discharge Welder* project (*Practical Electronics*, March and April 2023), where I wanted to check the resistance of the leads. Theory said they should be 8mΩ (spoiler alert – with the cables and handles, our welder leads measured 10mΩ).

Your garden variety multimeter won't measure anywhere near that low. Even my fancy, expensive meter was way off the mark. So what do you do when you want an accurate measurement of a really low resistance? You reach for your trusty old low-ohms meter.

Like many journeys in life, this design started on one path but ended up somewhere else. The initial plan was to update a previous milliohm meter design, adding a digital front end and making it easy to use. But halfway through, somebody said: why not make it measure up to 20MΩ? This added a bit of a spin on the design, but we think the result is a very handy and versatile device.

So here we have a design for a meter that will measure resistances from a couple of milliohms to 20 megohms, with precision significantly better than 1% across that range. Using 0.1% resistors for calibration (which we recommend), we have seen precision in the region of 0.1% across most of its range.

The trouble with multimeters

The problem with a standard multimeter is that the lead and banana socket resistance is usually in the 0.2-0.5Ω range. The variability in these resistances are too high to zero them out.

Ohm's Law is one of the first equations you learn in electronics. It is therefore not surprising that this principal is used in most ohmmeters, with the resistance measured using a constant-current source and a voltmeter. A typical multimeter combines these inside the meter and uses two leads, as shown in Fig.1.

When measuring a low resistance this way, the constant current needs to flow through the banana plugs, leads and from your lead tips into the device you are measuring, then back again. The voltage drops created by their inherent resistances all appear to the multimeter to be part of the measured resistance. This results in significant errors in low-resistance measurements.

There are other ways to measure resistance accurately that don't use this principle. For example, the Wheatstone bridge is a very elegant approach that can be highly accurate. But an automated meter based on one of those would be very complicated. If you are interested in this use for a Wheatstone Bridge, Wikipedia is a good place to find out more.

Kelvin connections

A four-wire measurement technique can be used to minimise these errors. Two wires deliver a known current through the device under test, while the second pair measure the voltage across the device under test (DUT), as shown in Fig.2. This neatly avoids the majority of errors above.

By using a constant-current source, even if there are lead and connection resistances, the current is always as expected. The voltmeter is chosen to have a high input resistance, so when the voltage measurement leads are connected across the DUT, even if the connection is a bit dodgy, we still read the correct voltage, and the $R = V / I$ calculation avoids the majority of errors.

There is a bit more effort involved in making really accurate resistance measurements than just adding two wires, but they are necessary to measure values well under 1Ω accurately.

You might wonder why all ohmmeters don't work this way if it is so effective. Well, using a four-wire ohmmeter

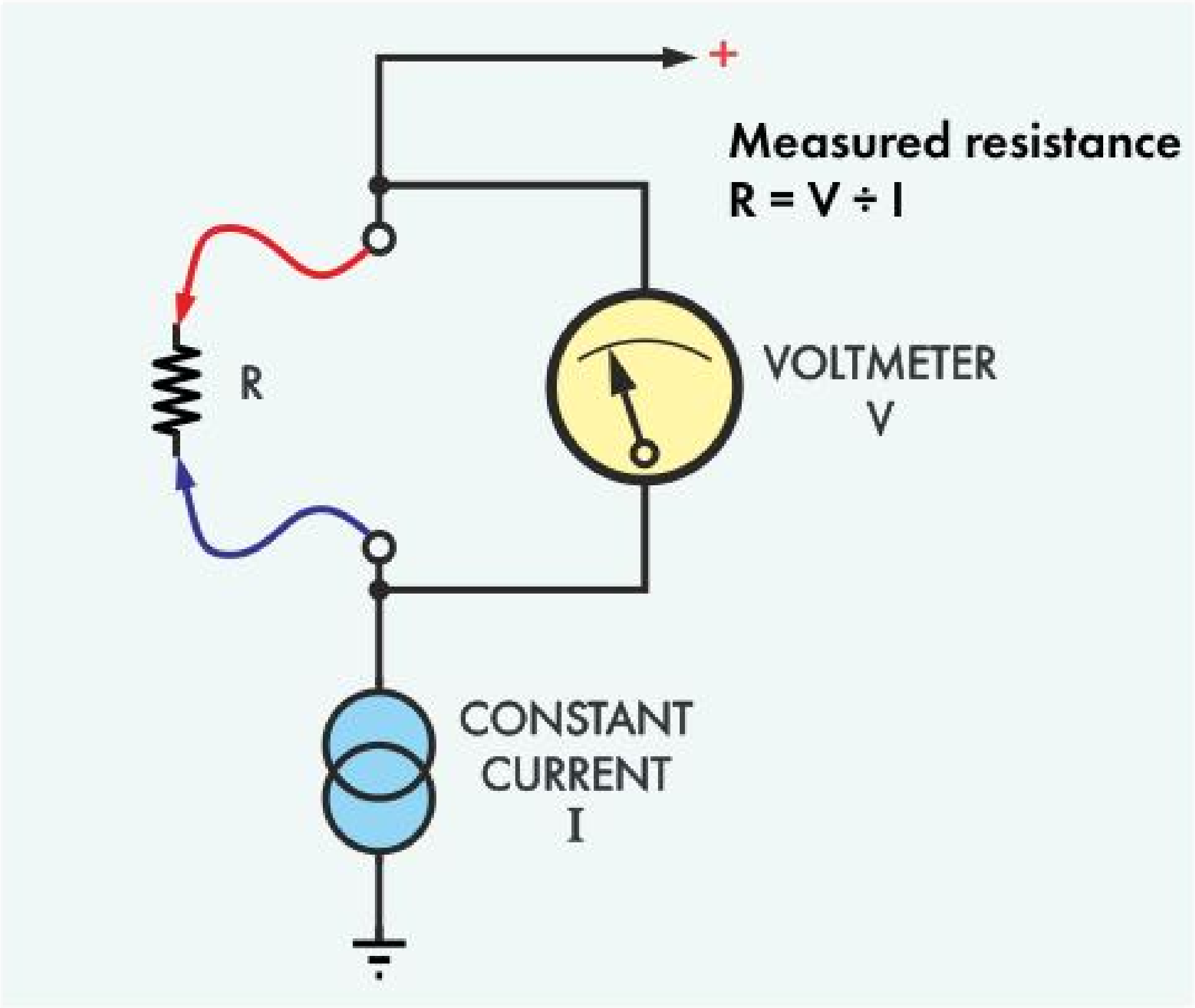


Fig.1: a standard ohmmeter works by passing a known, fixed current through the device under test (DUT), measuring the voltage across it, then using Ohm's Law to determine its resistance. The problem is that the test lead resistances are in series with the DUT and included in the result.

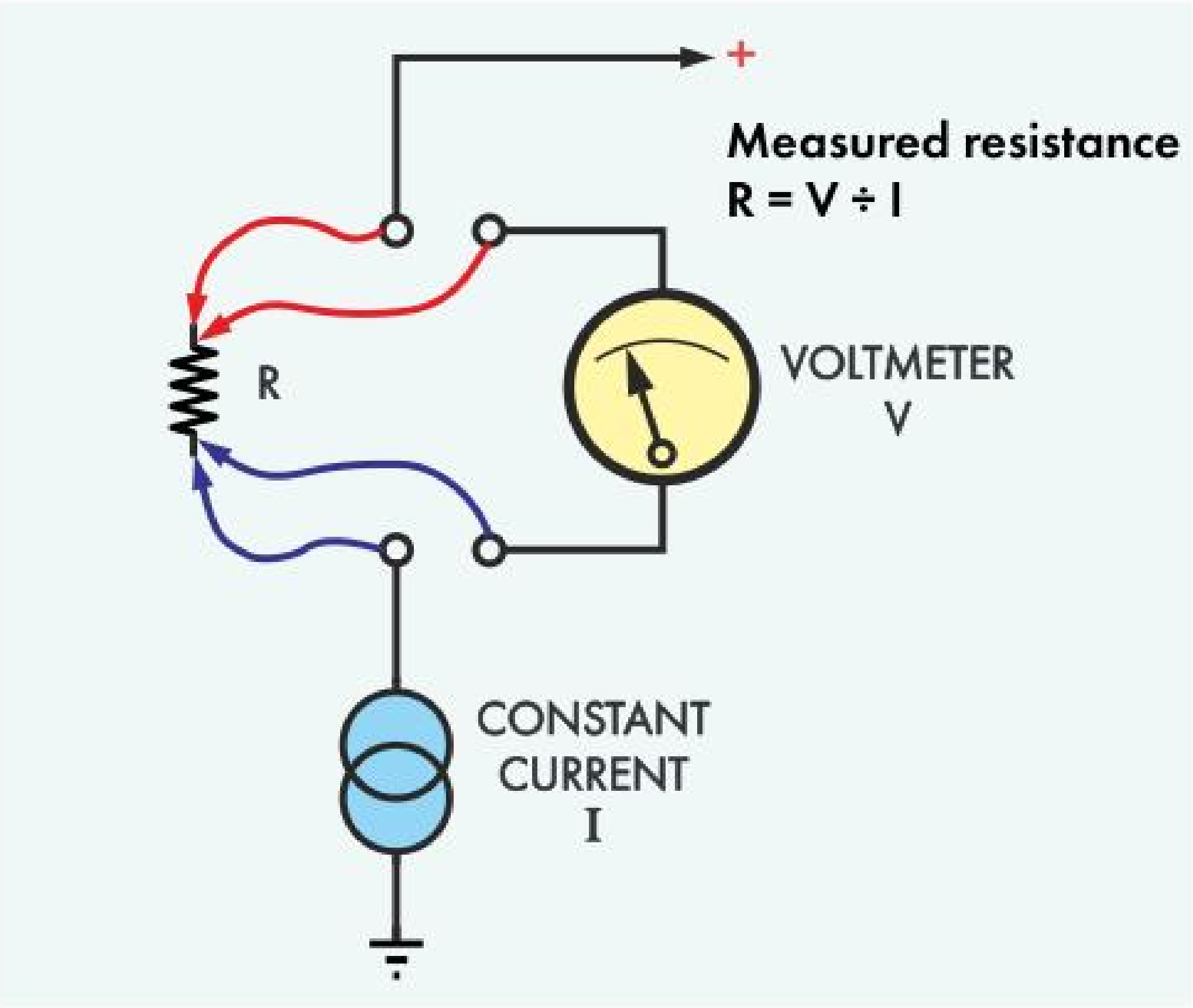


Fig.2: two pairs of leads are used with Kelvin connections, one to feed the test current to the DUT and one to sense the voltage across it. The voltage drop across the leads supplying current no longer affects the reading, and the voltage drop across the other pair of leads is so tiny that it doesn't matter.

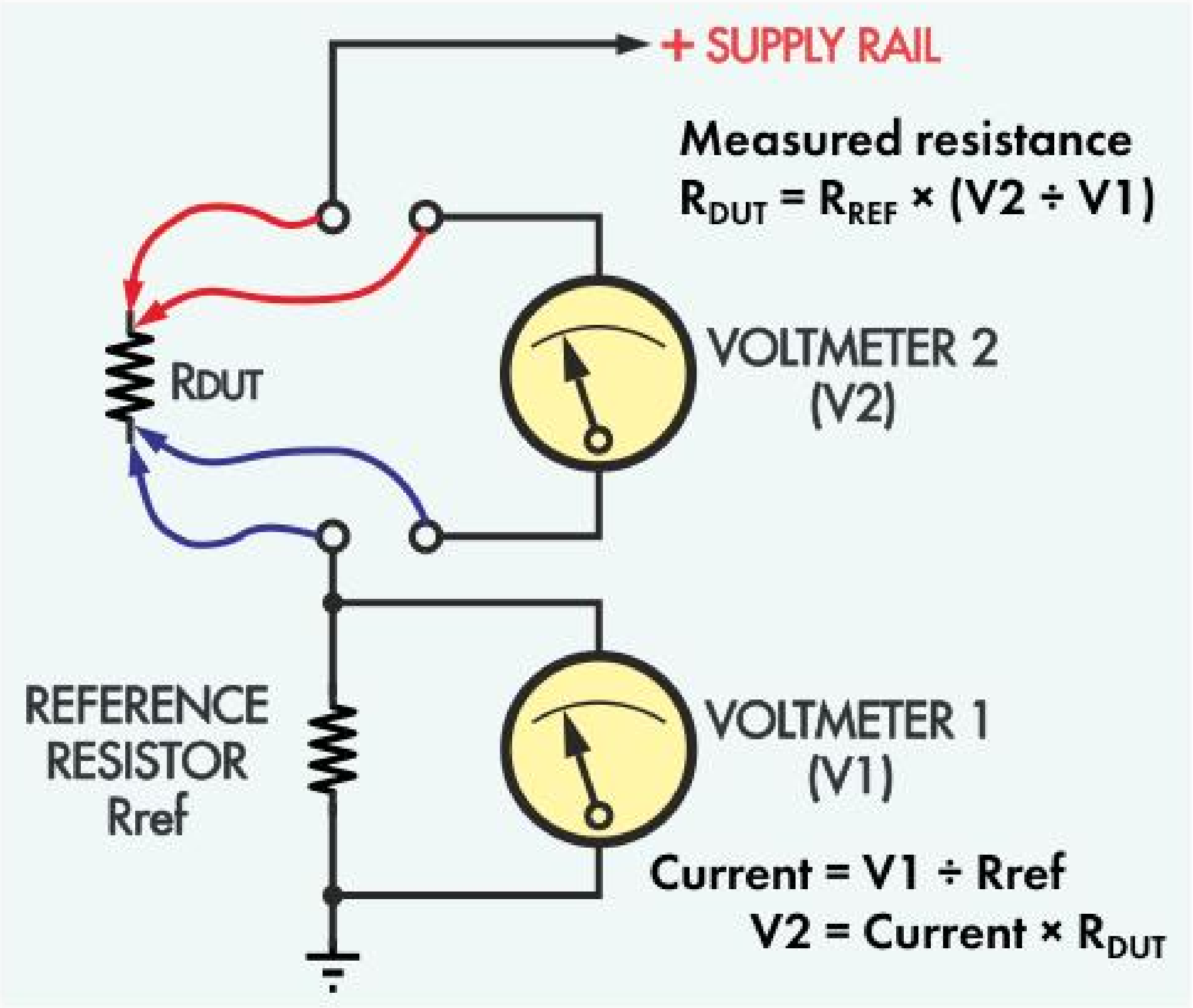


Fig.3: the problem with using the method shown in Fig.2 to measure high resistances is that the test current needs to be really low. So we use this method instead, where the DUT and a fixed resistor form a divider, and we measure the DUT resistance in proportion to the fixed resistor value.

is fiddly. There are four wires and most of us only have two hands. Also, the errors are no longer significant above a few hundred ohms. Therefore, all but a few meters (mainly benchtop meters, but some handheld) use the conventional two-wire approach.

The four-wire connection is called a 'Kelvin connection' after Lord Kelvin, who invented this to measure low resistances in 1861.

While working on this meter, we noticed some nice 'Kelvin clip leads' available at reasonable prices. These are essentially crocodile clips with two connections, one for the current source and the other for the sense wire. We found that these worked well over the range of our meter, though for really low resistances, four separate wires will give better accuracy.

Other challenges

We need to know the exact current through the DUT and the voltage across it. For DUTs with a low resistance, both of these are easily achieved. We use an LT3092 programmable current source and, as the voltmeter, an analogue-to-digital converter (ADC) with a carefully designed voltage reference.

These both provide good long-term stability for the meter and the ability to use 0.5mA and 50mA bias currents, which give measurements accurate into the low-milliohm range.

Measuring down to about 1mΩ is practical with a reasonably simple meter. This is about the lower limit before other factors become problematic. Even with higher currents, low resistances mean we need to measure low voltages. Our design uses special very-low-offset and very-low-drift operational amplifiers.

If we had chosen, say, a common TL074, the worst-case input offset of 4mV would introduce errors of up to 80mΩ on the low-ohms range! The device selected has a worst-case offset of 8μV over its entire operating temperature range, which still could result in an offset error of up to 1.6mΩ (although we have not seen anything like this sort of error in our testing).

This allows our meter to accurately measure a 5mΩ shunt resistor, which we feel is pretty good. To go beyond this, design approaches that null out these offsets are required – this is usually achieved by switching the current source on and off, allowing subtraction of the nil current offset. By using low-offset parts, we can avoid the need to do this in our design.

Megohms measurements

Adding a megohm range would seem to be a simple matter of setting the constant-current source to a very low current and making the exact same measurement. This is true, provided you can generate a stable current source delivering about 0.1μA with an output resistance much greater than 20MΩ. But that is not easy to achieve.

To avoid this, we use a slightly different technique for measuring higher resistances, as shown in Fig.3.

We use a high-value precision resistor to establish the test current. Because this is in series with the DUT, the current flowing will depend on the DUT's resistance.

We do not try to control the current; instead, we measure the voltage across the reference resistor to measure the current flowing for every measurement. By also measuring the voltage across the DUT, we have all the information we need to determine its resistance in proportion to the sense resistor.

For the 1MΩ range, we use a 1MΩ sense resistor. The current through this will vary. If we measure a 1MΩ resistor, the current will be $I_{TEST} = V_{SUPPLY} \div (R_{REF} + R_{DUT})$, about 1.5μA. Keep in mind that $I_{TEST} = V1 \div R_{REF}$. This relationship is handy, as we will see in a minute.

Ohm's Law tells us that the resistance of the DUT is defined by $R_{DUT} = V2 \div I_{TEST}$, where V2 is the voltage across the DUT. Combining this and the previous equation: $R_{DUT} = V2 \div (V1 \div R_{REF}) = R_{REF} \times (V2 \div V1)$.

Our ADC does not have two channels, but it does have an independent reference (V1) and measurement input (V2). So by connecting our ADC reference across the reference resistor, we can measure the ratio of V1 and V2 with the ADC, and it simply comes out as the measured value!

An added bonus of this approach is that we don't need to care about the exact supply rail voltage or exact current through the DUT.

The catch here is that our measurement of the voltages across the reference and DUT resistors has been assumed to be ideal, ie, our ADC has no impact on the current flowing through the DUT.

We already know that the current will be in the region of 0.1μA, so the ADC measuring the reference and DUT voltages needs to have very high input resistances and very low bias currents (the current flowing into or out of the input), or else the above assumption will fail.

The ADC we have chosen, the MAX11207, only has a bias current of 30nA. The voltage 30nA will develop across a 10MΩ resistor is $30 \times 10^{-9} \times 10 \times 10^{6} = 300 \times 10^{-3}$V, or 0.3V. This is a massive error, given that we will be measuring about 1.5V.

So we had to add a buffer amplifier with a super-low bias current. Our choice, the MCP6V64, has a typical input bias current of 20pA and a maximum offset current of 200pA (the difference between the bias currents for the + and – inputs). Given the current IC shortages, we have listed a few alternatives that we have tested in the parts list, but the MCP6V64 is our first choice.

This reduces the error with a 10MΩ resistor to $200 \times 10^{-12} \times 10 \times 10^{6} = 2 \times 10^{-3}$V or 3mV, a much more manageable error.

Circuit description

Let's look at how these decisions come together in our final design. The complete circuit is shown in Fig.4.

The heart of this meter is the MAX11207 20-bit ADC. We have also tested this with the similar MAX11210 chip, and the MAX11206 and MAX11200 should also work just fine too. We chose this device as it is very linear, provides great resolution and is available in several pin- and software-compatible forms.

It also has fully differential inputs for both the ADC and the reference, which can operate across the entire input range. This means we can pull some tricks and use the reference input in a somewhat unusual manner for high-resistance measurements.

This device has a range of settings, the most important ones being internal calibration and internal buffering. The software looks after this, and you should only notice a slight delay at power-on as they are initialised.

All the inputs to the ADC are buffered by the MCP6V64 quad operational amplifier. This device provides a very high input impedance, low bias current and low drift buffer for the ADC. All of its inputs and outputs can go close to the supply rails. Its key feature is bias currents in the pA range, and it can operate within 200mV of the rails.

When you get to the construction stage, take note that the PCB must be very clean around this surface-mount IC. Flux and residue from soldering can increase the leakage currents on these extremely high impedance inputs, degrading the performance of your meter. Thoroughly cleaning and coating this area with clear protective lacquer is an essential step in construction.

We have included 10kΩ series protection resistors from the sense inputs to the buffers, and a 10nF capacitor across the sense inputs, providing modest protection to the circuit. That said, we strongly suggest that you do not connect the meter to live circuits, as the application of more than a few volts between the terminals could easily cause damage.

On the milliohms range, the reference voltage going to the REFP input (pin 5) of IC1 via buffer IC2a comes from an LM336 2.5V shunt regulator, IC5 (lower left). We're specifying the LM336B type as it has tighter tolerances. The LM336 is set up with series diodes and a trimpot, which allows us to set it to exactly 2.50V, and the diodes minimise its drift with temperature.

The reference input is connected across a resistor of either 100kΩ, 1MΩ or 20MΩ resistors on the higher ranges. These can be found near IC5. The stability of these resistors is important for the accuracy of these ranges. Again, we will be calibrating the device, so initial precision is less critical than stability for these parts.

The MCP6V64 buffers for the ADC (IC2b and IC2c) can drive to within a few millivolts of the rails, but not quite to the rails. To accommodate this, the 2.50V voltage reference and reference resistors connect to ground through D8, a BAT85 schottky diode. Similarly, the DUT connects to the positive rail through D4, a 1N5819 schottky diode. These drop about 0.3V at the currents we operate them.

We use a constant-current device (IC3) to pass either 0.5mA or 50mA through the DUT on the milliohms and ohms ranges. The stability of the voltage and current references is essential to the accuracy of these ranges. But because we calibrate this meter against known resistors, absolute precision is less of an issue.

With a 3.6V supply rail, the maximum voltage that we can handle across the DUT is 1.7V. This is calculated by subtracting the voltage drops from the supply rail due to diode D4 (0.3V) and IC3 (1.6V). Let's say we can allow up to 1.5V across the DUT to be safe. This means a maximum reading of 1.5V ÷ 50mA = 30Ω on the milliohms range, and 1.5V ÷ 0.5mA = 3kΩ on the ohms range.

The maximum readings on the other ranges are limited by the values of the 100kΩ, 1MΩ and 20MΩ reference resistors.

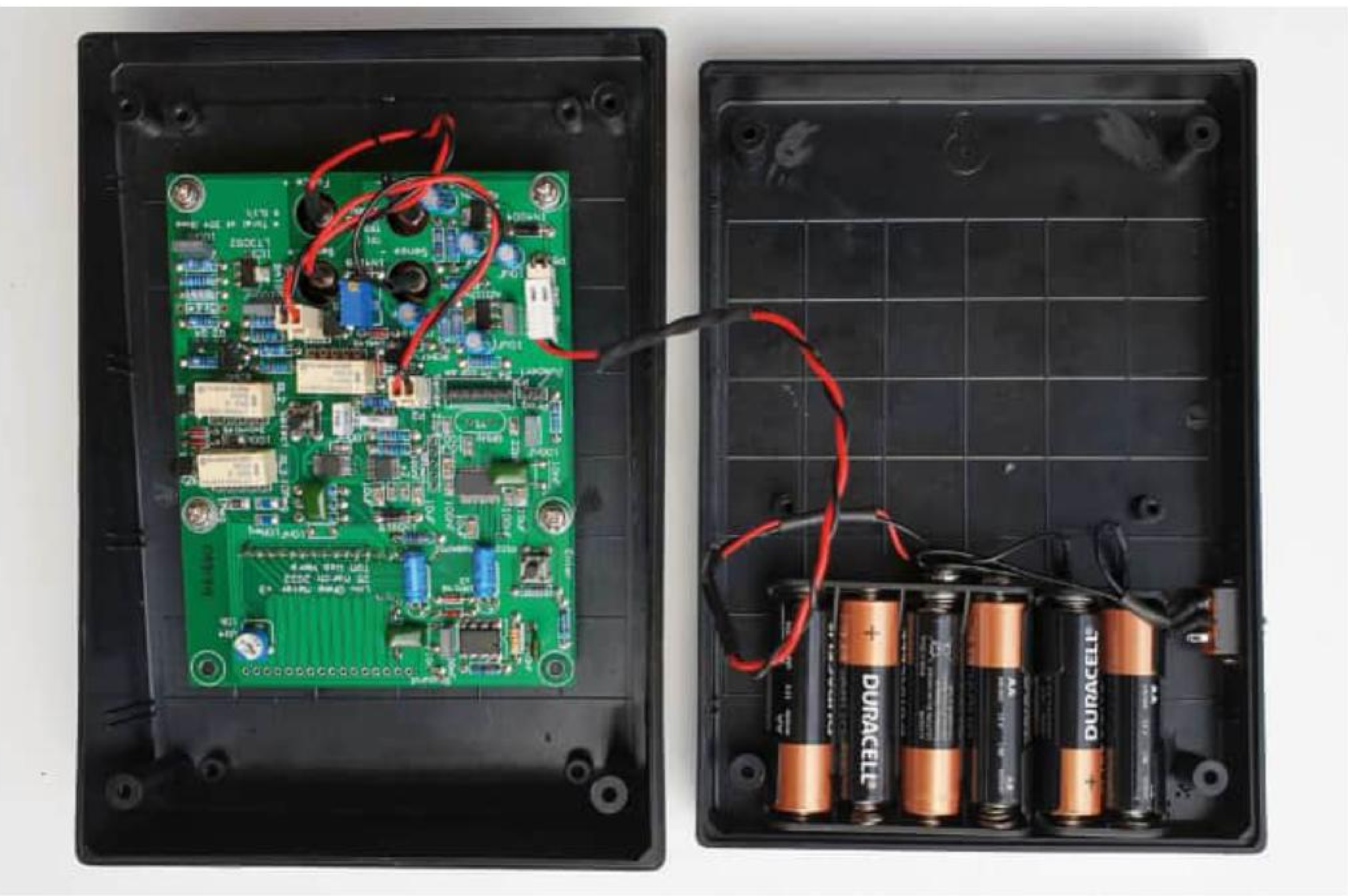
The current regulator

For the higher current (lower resistance) ranges (milliohms and ohms), we use IC3, an LT3092 constant-current source. We have chosen this for its long-term stability and ease of use. This device sources a constant 10µA from its SET pin, and the OUT pin is maintained at the same voltage as the SET pin.

With a 10kΩ resistor from the SET pin to GND, there will be 0.1V across it (10kΩ × 10µA). The parallel combination of 205Ω, 47kΩ and 1.5MΩ resistors results in 204.08Ω between the OUT pin and ground, giving a current of 490µA. Therefore, the IN pin sinks 490µA + 10µA = 500µA for these two currents combined, which is our goal (0.5mA).

For the milliohms range, parallel MOSFETs Q2 and Q4 switch on, so the two series 1Ω resistors are connected in parallel with the 204.08Ω resistance. But note that the on-resistance of the MOSFETs (40mΩ || 40mΩ = 20mΩ) adds to the 2Ω from the resistors. With 2.02Ω in parallel with 204.08Ω, we get 2.0002Ω. Thus the current from the OUT pin will be 49.99mA + 0.01mA or 50mA.

This way, the software can switch the constant-current source between 0.5mA and 50mA to suit the resistance detected on the meter by controlling the gates of Q2 and Q4.



A preview to part two, showing how the batteries and PCB are mounted.

Parts List – Wide-Range Ohmmeter

1 double-sided PCB coded 04109221, 90.5 × 117.5mm available from the *PE PCB Service.*
1 189 × 134 × 55 sloping ABS instrument case **[Altronics H0401]**
2 3 AA cell battery holders with leads **[Altronics S5033 + P0455]**
1 backlit 16×2 character alphanumeric LCD screen with HD44780-compatible controller (LCD1)
2 4-pin tactile switches (S1, S2)
1 subminiature DPDT solder tag slide switch with mounting screws (S3) **[Altronics S2010 + S2014]**
3 Omron G6H-5V or G6S-5V telecom relays or equivalent (RLY1-RLY3) [eg, Altronics S4128B]
1 10kΩ top-adjust multi-turn trimpot (VR1)
1 10kΩ top-adjust mini trimpot (VR2)
1 2-pin header with jumper shunt (JP1) (**optional**; only needed for in-circuit programming)
2 2-way vertical polarised headers with matching plugs (CON1, CON2) **[Altronics P5492 + P5472 + 2 x P5470A]**
1 16-pin header (CON3; for mounting the LCD)
1 6-pin header (CON4) (**optional**; only needed for in-circuit programming)
1 2-pin right-angle polarised header with matching plug (CON5) **[Altronics P5512 + P5472 + 2 x P5470A]**
1 5-pin header (CON6) (**optional**; for monitoring SPI)
2 red captive head binding/banana posts (CON7, CON8) **[Altronics P9252]**
2 black captive head binding/banana posts (CON9, CON10) **[Altronics P9254]**
various lengths of light-duty hook-up wire
1 pre-made set of Kelvin clip leads
OR
1 DIY set of Kelvin clip leads (see section below)

Hardware
4 M3 × 10mm tapped metal spacers
4 M3 × 6mm panhead machine screws
4 M3 × 6mm countersunk head machine screws
8 M3 shakeproof washers
1 small tube of clear neutral-cure silicone sealant
1 can of PCB conformal coating/protective lacquer

Kelvin clip leads (if not using pre-made leads)
2 Kelvin alligator clips **[Mouser 485-3313 or 510-CTM-75K; Digi-Key 1528-2279-ND]**
1 2m length of 17AWG (1.0mm^2) black figure-8 cable **[Altronics W4146]** ***OR***
1 2m length of two-core heavy-duty microphone cable **[Altronics W3028]**
1 1m length of 18AWG (0.75mm^2) red silicone high-temperature hook-up wire **[Altronics W2400]**
1 1m length of 18AWG (0.75mm^2) black silicone high-temperature hook-up wire **[Altronics W2401]**

Semiconductors
1 MAX11207EEE+ 20-bit ADC, QSOP-16 (IC1) (alternatives exist – see text)
1 MCP6V64-E/ST quad low-drift rail-to-rail op amp, TSSOP-14 (IC2) ■
1 LT3092EST or LT3092IST programmable current source, SOT-223 (IC3)
1 PIC24FJ256GA702-I/SS 16-bit microcontroller programmed with 0410922A.HEX, SSOP-28 (IC4)
1 LM336BZ-2.5/NOPB voltage reference, TO-92 (IC5)
1 555 timer, DIP-8 (IC6)
2 AZ1117H-ADJTRG1, AMS1117 or equivalent adjustable 1A LDO regulators, SOT-223 (REG1, REG2)
4 BC547 100mA NPN transistors, TO-92 (Q1, Q3, Q5, Q6)
2 IRLML0030TRPBF N-channel MOSFETs, SOT-23 (Q2, Q4)
7 1N4148 75V 250mA signal diodes (D1, D2, D5-D7, D10, D11)
2 1N5819 40V 1A schottky diodes (D3, D4)
1 BAT85 30V 200mA schottky diode (D8)
1 1N4004 400V 1A diode (D9)

Capacitors
7 10µF 50V radial electrolytic
5 10µF 16V X7R SMD M3216/1206-size ceramic
5 100nF 50V X7R through-hole ceramic
5 100nF 50V X7R SMD M2012/0805-size ceramic
2 10nF 100V PPS **[Kemet SMR5103J100J01L16.5C]**
4 10nF 50V X7R through-hole ceramic

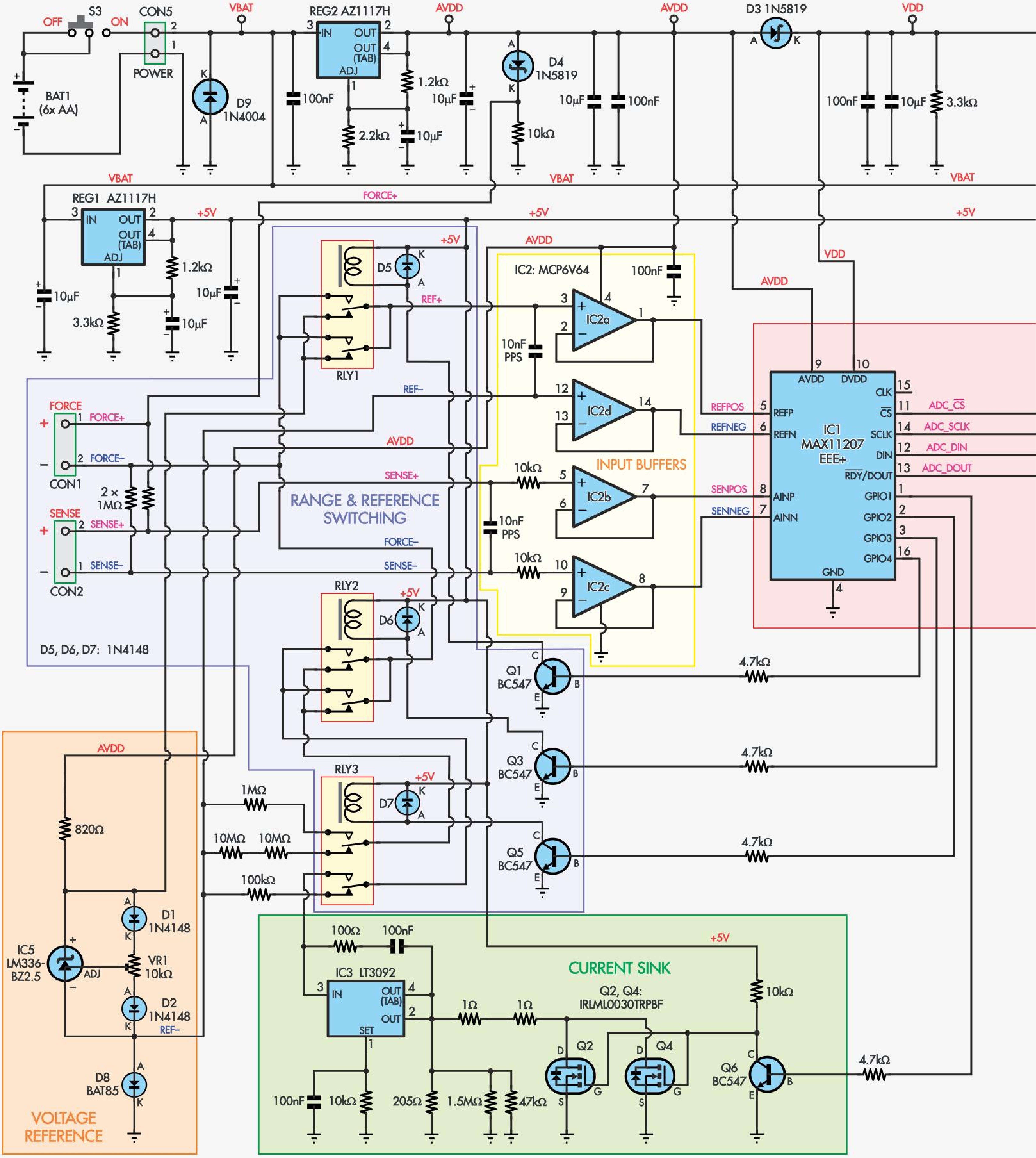
Resistors *(all axial 1/4W 1% metal film unless noted)*
2 10MΩ 0.1% 25ppm SMD M3216/1206-size
1 1.5MΩ
1 1MΩ 0.1% 25ppm SMD M3216/1206-size
2 1MΩ 1% SMD M2012/0805-size
1 100kΩ 0.1% 25ppm SMD M3216/1206-size
1 47kΩ
1 33kΩ
1 22kΩ
1 10kΩ 0.1% 15ppm
7 10kΩ
4 4.7kΩ
3 3.3kΩ
1 2.2kΩ
2 1.2kΩ
1 820Ω
1 205Ω 0.1% 15ppm
2 100Ω
1 47Ω
2 1Ω 1% 50ppm

Calibration resistors *(not required if another high-precision ohmmeter is available)*
1 27.4Ω ¼W 0.1% 15ppm axial **[YR1B27R4CC]**
1 2.94kΩ ¼W 0.1% 15ppm axial **[YR1B2K94CC]**
1 97.6kΩ ¼W 0.1% 15ppm axial **[YR1B97K6CC]**
1 976kΩ ¼W 0.1% 15ppm axial **[YR1B976KCC]**
1 10MΩ ¼W 1% 50ppm axial **[MF0204FTE52-10M]**

■ *compatible op amps need to be rail to rail, unity-gain stable with very low input offset voltages and input bias currents in a TSSOP-14 package. Good alternatives are the MCP6V79, MCP6V34 and OPA4317.*

We recommend using 0.1% 15ppm resistors for the 10kΩ and 205Ω parts, as specified in the parts list. We found 1Ω 0.1% resistors too expensive, so we used 1% parts instead. These are MF0207FRE52-1R, which have a 50ppm temperature coefficient, so they should be pretty stable.

We have provided the current source with a good heatsink in the form of a large copper fill on the top layer of the PCB. The keen-eyed will also note that


S3
OFF
ON
CON5
POWER
BAT1 (6x AA)
VBAT
REG2 AZ1117H
IN
OUT
OUT (TAB)
ADJ
AVDD
D3 1N5819
VDD
D4 1N5819
D9 1N4004
100nF
1.2kΩ
10μF
2.2kΩ
10kΩ
3.3kΩ
REG1 AZ1117H
+5V
FORCE+
IC2: MCP6V64
IC2a
IC2b
IC2c
IC2d
10nF PPS
INPUT BUFFERS
RLY1
RLY2
RLY3
D5
D6
D7
REF+
REF–
FORCE
FORCE–
CON1
SENSE
SENSE+
SENSE–
CON2
2 × 1MΩ
RANGE & REFERENCE SWITCHING
D5, D6, D7: 1N4148
IC1 MAX11207 EEE+
REFPOS
REFNEG
SENPOS
SENNEG
REFP
REFN
AINP
AINN
CLK
CS
SCLK
DIN
RDY/DOUT
GPIO1
GPIO2
GPIO3
GPIO4
GND
ADC_CS
ADC_SCLK
ADC_DIN
ADC_DOUT
Q1 BC547
Q3 BC547
Q5 BC547
4.7kΩ
1MΩ
10MΩ
100kΩ
820Ω
D1 1N4148
D2 1N4148
VR1 10kΩ
IC5 LM336-BZ2.5
ADJ
D8 BAT85
VOLTAGE REFERENCE
100Ω
IC3 LT3092
SET
CURRENT SINK
Q2, Q4: IRLML0030TRPBF
Q2
Q4
Q6 BC547
1Ω
205Ω
1.5MΩ
47kΩ

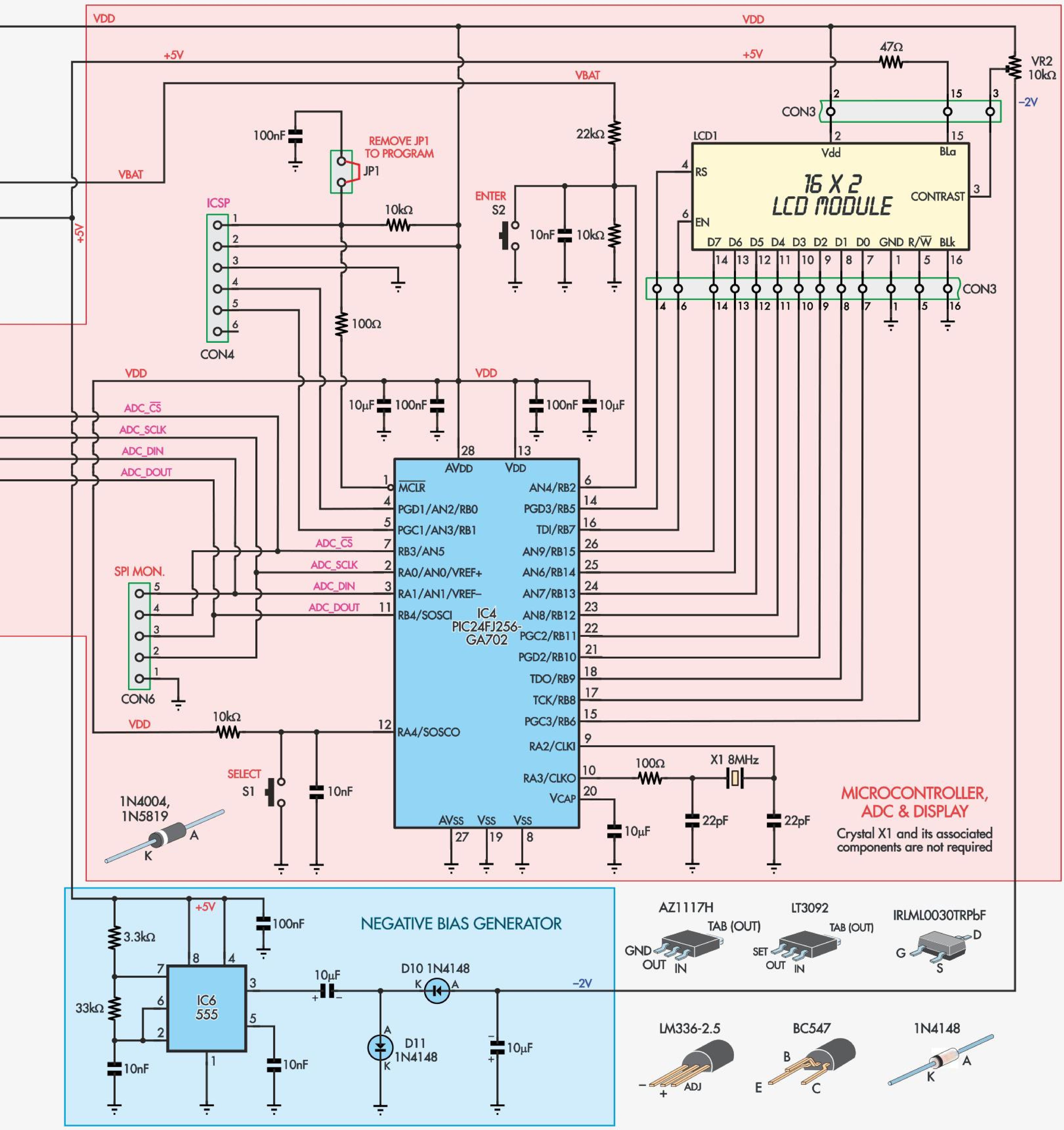
Wide-range Digital Ohmmeter

Fig.4: all measurements are made by IC1, the ADC, controlled by microcontroller IC4. IC4 switches relays RLY1-RLY3 to select the appropriate range and displays readings on the 16x2 LCD module. Voltage reference IC5 is used in the lower (milliohms and ohms) ranges, while IC3 regulates the test current, with MOSFETs Q2 and Q4 switching it between 0.5mA and 50mA. In ratiometric (high-range) mode, IC3 and IC5 are not used, and precision resistors of 100kΩ, 1MΩ or 20MΩ are connected in series with the DUT.

we have placed a guard track around the SET pin, which has an extremely low current flowing from it. This reduces leakage currents interfering with our carefully-designed current source.

The reference resistors

We measure resistances in three ranges above 3kΩ: 100kΩ, 1MΩ and 20MΩ. Our measurement technique uses reference resistors at each of these values. We have specified parts that should provide a low temperature coefficient and long-term stability. We again recommend 0.1% parts where reasonable.


VDD
+5V
VBAT
100nF
REMOVE JP1 TO PROGRAM
JP1
22kΩ
47Ω
VR2 10kΩ
CON3
–2V
LCD1
16 X 2 LCD MODULE
Vdd
BLa
RS
EN
CONTRAST
D7 D6 D5 D4 D3 D2 D1 D0 GND R/W BLk
ICSP
CON4
10kΩ
ENTER S2
10nF
10kΩ
100Ω
ADC_CS
ADC_SCLK
ADC_DIN
ADC_DOUT
10µF
100nF
AVDD
VDD
MCLR
PGD1/AN2/RB0
PGC1/AN3/RB1
RB3/AN5
RA0/AN0/VREF+
RA1/AN1/VREF–
RB4/SOSCI
IC4 PIC24FJ256-GA702
AN4/RB2
PGD3/RB5
TDI/RB7
AN9/RB15
AN6/RB14
AN7/RB13
AN8/RB12
PGC2/RB11
PGD2/RB10
TDO/RB9
TCK/RB8
PGC3/RB6
RA2/CLKI
RA3/CLKO
VCAP
RA4/SOSCO
AVSS
VSS
SPI MON.
CON6
SELECT S1
1N4004, 1N5819
A
K
X1 8MHz
22pF
MICROCONTROLLER, ADC & DISPLAY
Crystal X1 and its associated components are not required
NEGATIVE BIAS GENERATOR
3.3kΩ
33kΩ
IC6 555
10nF
D10 1N4148
D11 1N4148
AZ1117H
TAB (OUT)
GND
OUT
IN
LT3092
SET
IRLML0030TRPbF
G
D
S
LM336-2.5
ADJ
BC547
B
E
C
1N4148

20MΩ tight-tolerance resistors are both expensive and uncommon, so we use two 10MΩ resistors in series. Stability is probably more important than actual precision, as the meter will be calibrated.

Again, cleaning off all flux and residue around these is very important, as is coating it with a protective lacquer to optimise long-term stability. We used 3.2 × 1.6mm SMD parts here (M3216/1206) as our survey of suppliers found that 0.1% parts are more available and less expensive in these packages than in through-hole.

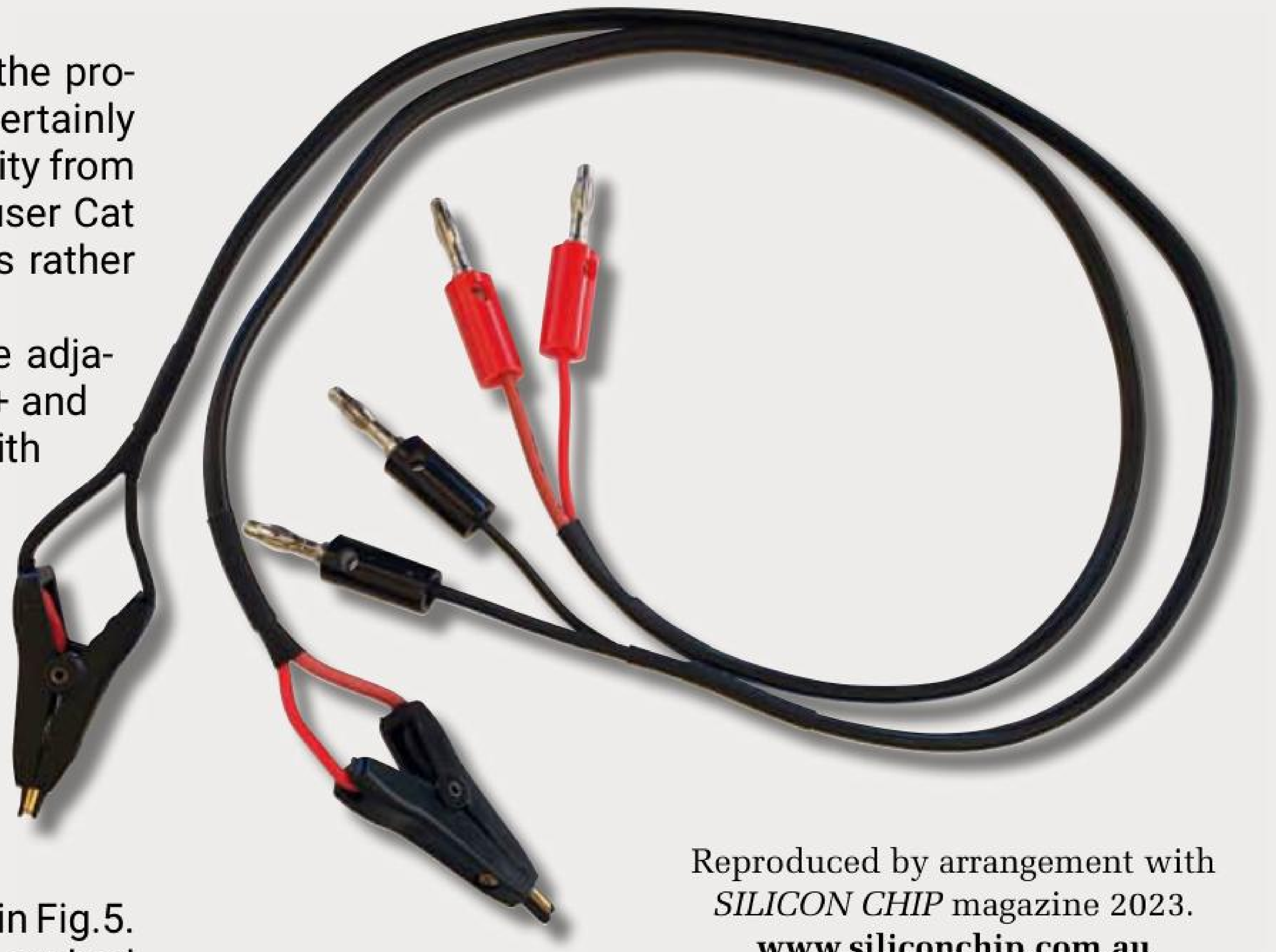
Switching the ADC inputs

Because we have five different ranges and can't handle any additional bias currents, we need to do some switching, and that's done with relays. The resulting switching arrangement might initially look complicated but there isn't too much to it. Regardless, the auto-ranging feature means that the user doesn't need to know the details.

One relay, RLY1, switches the reference input between the fixed 2.50V reference and the three reference resistors. The other two relays, RLY2 and RLY3, connect either the constant-current device (IC3) or one of the three reference resistors to the lower pin on the Force connector, CON1.

The PCB has been laid out to handle two of the most common types of signal relays, conforming to the Omron G6H and G6S layouts. These are available from a range of electronic

Kelvin leads



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We used Adafruit 3313 Kelvin clips leads with the prototype, which are amazingly cost-effective; certainly less expensive than a double espresso! Availability from the usual suppliers is mixed. We also tried Mouser Cat 510-CTM-75K, which is a delight to use but it is rather more expensive.

These are simple to wire up, as shown in the adjacent photo. All you need to do is wire the Force+ and Sense+ wires to either side of the '+' Kelvin clip (with the red wire) and the other two terminals to the remaining black wires of the '−' Kelvin clip. Keep in mind that the force and sense wires only contact either side of the DUT lead.

Where you measure larger or more fiddly items, separate force and sense test leads might be better. Again, the force current must run through the whole item you wish to measure the resistance of, and the sense lines are connected to measure the part you desire, as shown in Fig.5.

We made two sets of leads for our meter. One set had separate sense and force leads, and these are essentially conventional multimeter leads.

We made them using 18AWG silicone-coated high-temperature hook-up cable (Altronics W240X), which is very flexible. We connected these wires to clips for the force and probes for the sense lines.

We did not use these much in the end, as the Kelvin clips are excellent right down into the low-milliohm region.

We used Altronics Cat W4146 sheathed figure-8 flex for our Kelvin clips, though we feel that a lighter gauge would be easier to use if you can find it. We used coloured heatshrink tubing to clarify which wires are + and − (although this generally isn't important when making measurements). One Kelvin clip connects to 'Force −' and 'Sense −' while the other goes to the 'Force +' and 'Sense +' sockets on the meter.

The length of leads should not matter as the conductors are close, so any EMI picked up should mostly cancel out. We felt that 600mm was about right, but that is a matter of preference.

If you don't want to make up your own set of Kelvin clip leads, they are available to buy pre-made at reasonably low prices at sites like eBay. Search for 'LCR clip leads'.

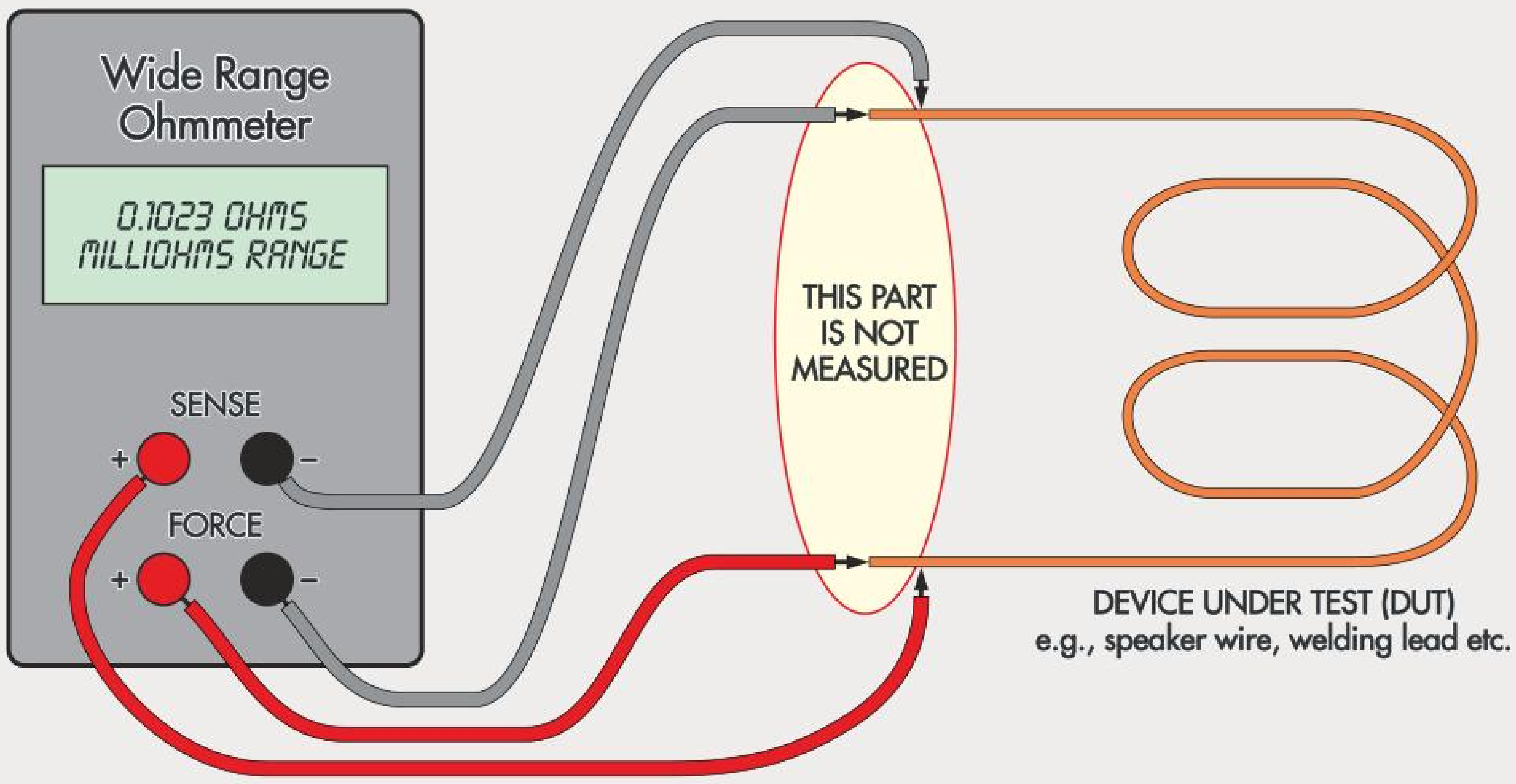

Fig.5: when working with Kelvin probes, it doesn't matter whether you connect the 'sense' leads closer to the DUT than the 'force' leads or not. Regardless, the section between the two connections on either side is not measured because current is flowing through it or the measurement point is further along.

outlets. Just make sure you use 5V non-latching versions.

Microcontroller and display

We have kept the display and control circuitry simple. We see this as a utilitarian device, so it should put function over form, and seek to 'do what it says on the box' as simply, cheaply and reliably as possible.

The LCD screen operates from the VDD rail of about 3.4V, but these displays are almost always powered from 5V. It turns out that the LCD bias between the VDD and VO pins on the LCD module needs to be about 5V, but the actual controller is specified to operate from 2.7V.

Therefore, we can generate a negative voltage of about −2V for the VO bias reference and power the LCD from the same VDD rail used for the PIC micro. The reason we need to do this is because some LCDs are incompatible with the 3.3V CMOS outputs from microcontrollers.

Annoyingly, it is very difficult to tell which LCDs work with 3.3V logic and which don't. To avoid this frustration, we have arranged the circuit so that all LCDs should work.

The negative VO bias is generated by 555 timer IC6, which oscillates at a couple of kilohertz. This drives a switched-capacitor voltage inverter comprising two 10µF capacitors and two 1N4148 diodes.

This runs off the relay 5V rail and generates −2V or so. By using the 5V rail, we avoid running this 'noisy' circuit from a rail used for the sensitive current sources and ADC.

User interface

The goal of simplicity has led us to remove all buttons from the front panel and implement an auto-range function. There are two buttons on the PCB which are only used for calibration; we will discuss them later.

Upon initial connection, the *Meter* will first check the DUT on the 100kΩ range. Depending on the result, it will increase or decrease the range appropriately until the optimal measurement range is found.

We start with the 100kΩ range as most of the resistors we measure seem to be less than this resistance. The way the *Meter* does auto-ranging means it will generally jump from the 100kΩ range straight to the final measurement range. The initial test current will be 30µA or less, and this will increase to 500µA for resistances between 30Ω and 100kΩ, or 50mA for resistances below 30Ω.

The highest possible power delivered is 75mW for a 30Ω resistor. This should be safe for all bar the most sensitive devices.

The microcontroller used is a PIC24FJ256GA702-I/SS. This is just right for the job in terms of pin count, though we also use four 'free' digital I/O pins provided on the ADC, as they were too convenient to ignore! We have used a simple schottky diode to drop the 3.6V rail to something closer to 3.3V for the ADC and the microcontroller, since 3.6V is right at their upper limits.

The micro drives a 16-column, two-line alphanumeric LCD with an HD44780-compatible controller. These are bog-standard but, as a result, come in a bewildering variety of layouts.

We have included two very common footprints on the PCB, which gives you some options for selecting a display. When you purchase the display, check the pin-out, as the LED backlight, in particular, seems to change around a lot.

Two headers need a comment. The first is the ICSP header, CON4. Insert the PIC and program it with a PICkit 3, 4 or 5 (soon to be released). The code is available for download from the August 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**

There is also a footprint for CON6, SPI_MON. You should definitely not need this unless you want to look at the SPI activity between the microcontroller and ADC. This sort of facility is super helpful when developing a project like this.

We also have pads for an external 8MHz crystal and associated 22pF and 100Ω passives, although these parts are not required in this design because we use the PIC's internal oscillator instead.

The ADC, buffer op amp and microcontroller are all surface-mount parts. They are simply not available in through-hole packages in the first two cases. We also had a desire to fit this project into a handy instrument case.

Power supply

The circuit operates from six AA cells. We chose this approach to ensure the meter would have a good runtime and that the 5V rail stays up as the batteries discharge.

The meter can draw close to 100mA when measuring low resistances. This should provide over 24 hours of runtime on a set of batteries, which will be fine provided you do not forget to switch it off overnight!

There are two linear low-dropout regulators. One has a 5V output to power the relay coils, LED backlighting on the LCD screen and the −2V generator (REG3). The other has a 3.6V output (REG2) to power the ADC, buffer op amps and micro. Both regulators are specified as the AZ1117 type, but there are many pin-compatible LDO regulators (usually with 1117 in their part code) that will work fine too.

We've provided all the components to allow two identical adjustable regulators to be used for REG2 and REG3. Still, you could use a fixed 5.0V output regulator for REG3, omitting the resistor between the OUT and ADJ pin and its series capacitor, and replacing the resistor between ADJ and GND with a 0Ω resistor (or a short piece of wire across the pads).

You could theoretically do that for REG2 as well, but unfortunately, 3.6V is not available as a fixed output option on this type of regulator. So stick with the adjustable type for REG2.

Next month

We don't have space in this issue for all the construction, testing and set-up details, so they will be in a follow-up article next month.

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By Charles Kosina

Atten
33 dB
Step 1
0-110 dB
ATTENUATOR

Features and Specifications

Usable frequency range: DC to 100MHz

Input and output impedance: 50Ω

Attenuation range: 0dB to –110dB in 1dB steps up to 2MHz; reduced maximum attenuation at higher frequencies (see Fig.2)

Attenuation error: typically ≤0.5dB (see Fig.1)

Power supply: 5V/100mA

Fits in the same diecast case as the AM/FM Signal Generator from May 2023

0-110dB RF Attenuator for Signal Generators

This RF Attenuator was designed to accompany my recently published AM/FM Signal Generator design (May 2023). However, you could combine it with just about any signal generator to provide easy output level adjustment over a wide range.

We often need a very low amplitude RF signal to test, align or adjust a radio. Unless you buy an expensive signal generator, the chances are that your generator's output level is far too high for such a task.

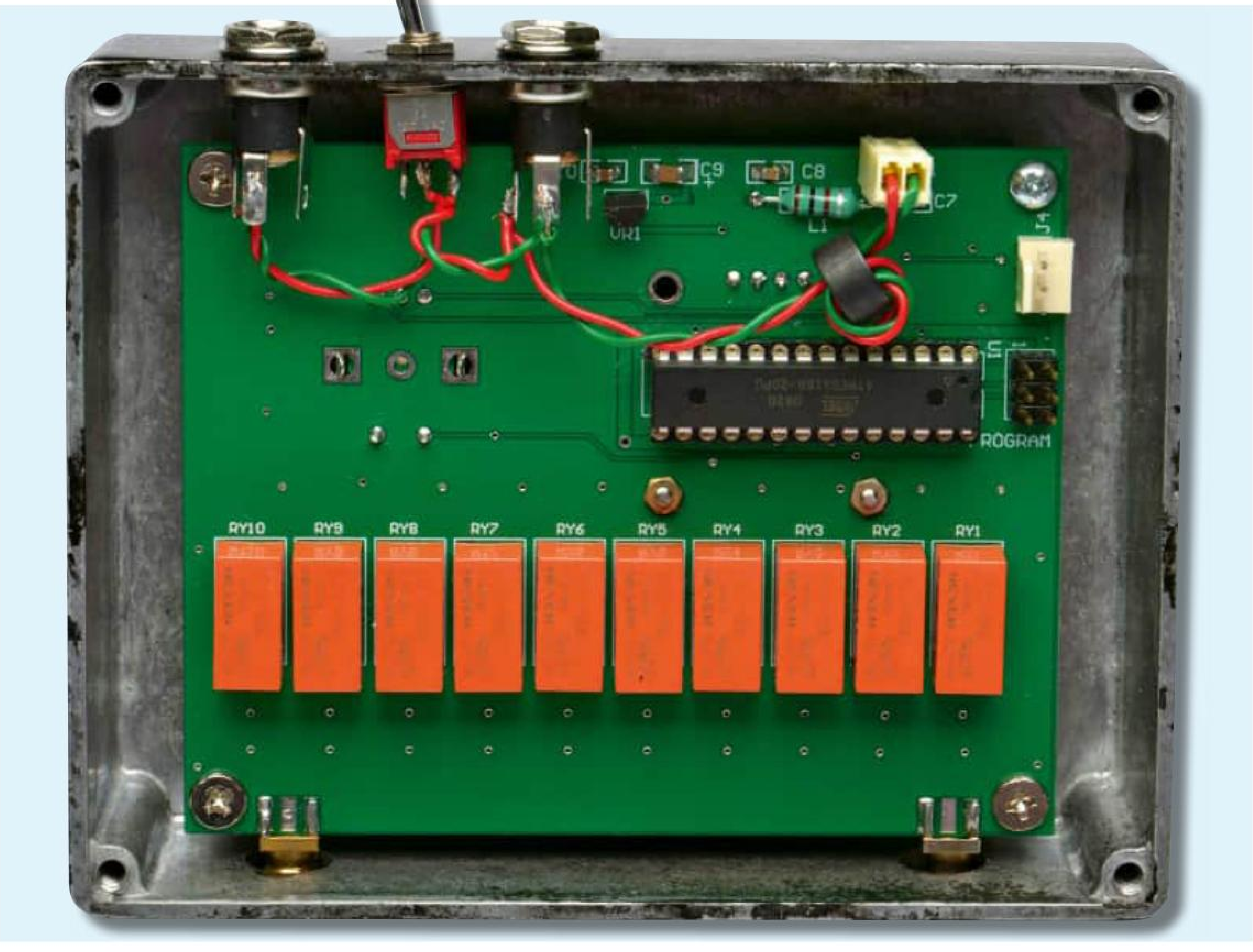
My recent *AM/FM Signal Generator* design has an output near 0dBm, which translates to about 220mV into a 50Ω load. To reduce this to 1μV RMS (eg, for testing a radio's sensitivity), we need 107dB of attenuation.

The simplest way to achieve this is to buy off-the-shelf fixed attenuators. These are available from 1dB to 40dB and cost a few pounds each. They have SMA connectors on either end, and you screw them together to give the required attenuation.

Variable digital attenuators are also available (reviewed by *Practical Electronics* last year, October and November 2022). These have a maximum attenuation of about 30dB and can be adjusted in small steps, eg, 1dB or 0.5dB. Combining one of these with a few fixed attenuators is one possible solution.

However, I decided to design my own attenuator as it is pretty straightforward; it's basically just a string of fixed attenuators, each consisting of three resistors, selected in combinations using relays.

This works fine at low frequencies – for example, below 2MHz – but once we get much higher than that, the signal will sneak through by various paths to make a 1μV output difficult to achieve.



Parts List – 110dB RF Attenuator

1 double-sided plated-through PCB coded CSE211003, 76 x 95.5mm, available from the *PE PCB Service*.
1 diecast aluminium enclosure, 119 x 93.5 x 34mm **[Jaycar HB5067 or Altronics H0454]**
1 5V 100mA+ regulated DC power supply (eg, USB charger with adaptor cable)
1 0.96-inch OLED screen module with I^{2}C interface and SSD1306 controller (OLED1)
1 mechanical rotary encoder with integrated pushbutton switch and 20mm total height (RE1) **[eg, Bourns PEC11R-4215F-S0024]**
10 EC2-5NU DPDT 5V coil relays (RLY1-RLY10)
1 10µH axial RF inductor (L1)
1 28-pin DIL IC socket (**optional**, for IC1)
1 PCB-mount DC barrel socket with 2.1mm or 2.5mm inner pin diameter (CON1)
1 2-pin, 2.54mm pitch-polarised header and matching plug with pins (CON2)
1 3-pin, 2.54mm pitch-polarised header (CON3) •
2 SMA edge connectors (CON4, CON5)
2 2x3-pin header (CON6; **optional**, for programming IC1)
1 4-way female header socket (CON7; for OLED1)
1 large knob to suit EN1
4 12mm-long M3 tapped metal spacers
2 10mm untapped spacers
4 M3 x 6mm panhead machine screws
4 M3 x 8mm countersunk head machine screws
2 M2 x 16mm or M2.5 x 16mm panhead machine screws and nuts (to match OLED mounting holes)
4 M3 flat washers

Semiconductors
1 ATmega168 or ATmega328 8-bit microcontroller programmed with CSE211003.hex, DIP-28 (IC1)
1 LP2950-3.3 or similar 3.3V LDO regulator, TO-92 (REG1)
10 PMV15UNEA, PMV19XNEA or similar avalanche-rated N-channel MOSFETs, SOT-23 (Q1-10) **[Mouser Cat 771-PMV15UNEAR or element14 Cat 3268027]**
2 2N7000 N-channel MOSFETs, SOT-23 (Q11-Q12) •

Capacitors *(SMD 0805 6.3V+ X7R ceramic unless stated)*
1 10µF M3216/1206-size
1 1µF
4 100nF
3 10nF

Resistors *(all SMD M2012/0805 1% thick film)*
5 18kΩ
2 470Ω
4 100Ω
1 18Ω
2 4.7kΩ
2 270Ω
2 68Ω
1 12Ω
1 1kΩ •
4 220Ω
8 56Ω
1 5.6Ω
2 820Ω
2 180Ω
1 33Ω

• *omit if the debugging interface is not needed*

Does this Attenuator achieve such a task? Yes and no. At 2MHz and below, the maximum attenuation is 110dB, but once we get to 75MHz, the attenuation is only 81dB. So for a 0dBm input, the lowest output level is 20µV RMS. However, adding one fixed 30dB attenuator to its output lets us get to 110dB and still gives quite a bit of adjustment range, so I consider that reasonably good.

This is because, at higher frequencies, stray capacitance and inductance become more significant. In addition, circuit board tracks act as antennas and radiate energy that is picked up further downstream in the attenuator string.

Professional signal generators with attenuators use extensive internal shielding to reduce such effects. For home-built equipment, this is somewhat impractical. That is why I did not build this *Attenuator* into my *Signal Generator* but rather in a separate diecast aluminium enclosure. There is far too much RF floating around in the signal generator, which would make it difficult to isolate the attenuator section.

Fig.3 shows the attenuator circuit. The signal is fed in via CON4, then passes through ten switched attenuator sections using DPDT relays (RLY1 to RLY10) before reaching output connector CON5. These sections attenuate by 1dB, 2dB, 3dB, 5dB, 10dB (twice) and 20dB (four instances).

The ideal resistance values for these attenuators are not in the standard range, so I have chosen the closest standard values, which do result in slight inaccuracies.

With a relay de-energised, the signal just passes through the normally-closed sets of contacts. If it is energised, the signal instead passes through the resistive attenuator section.

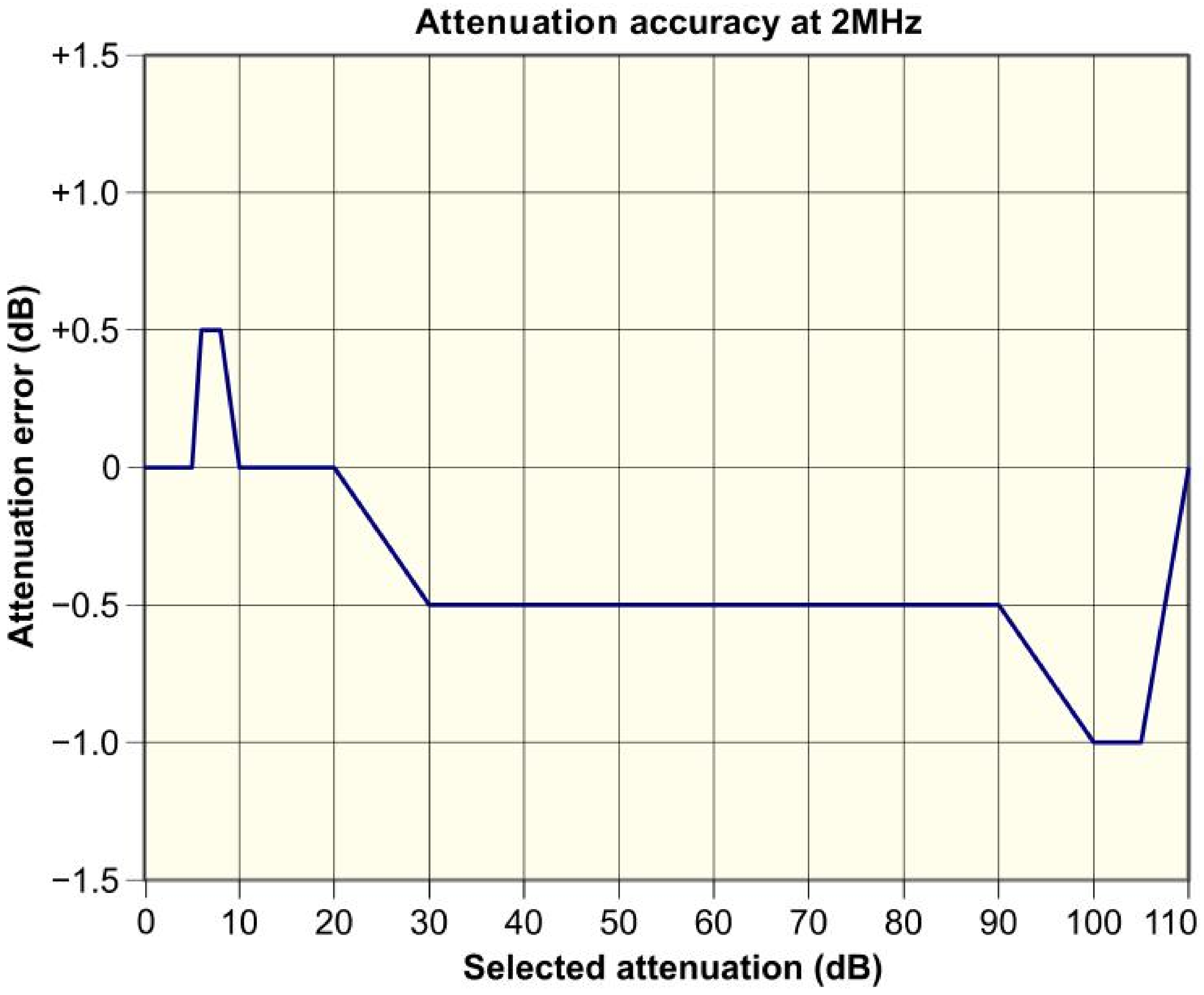


Fig.1: the attenuation settings are very accurate at low frequencies down to about 90dB, with a maximum error of only 1dB. The +0.5dB blip between 6dB and 8dB could be due to measurement error.

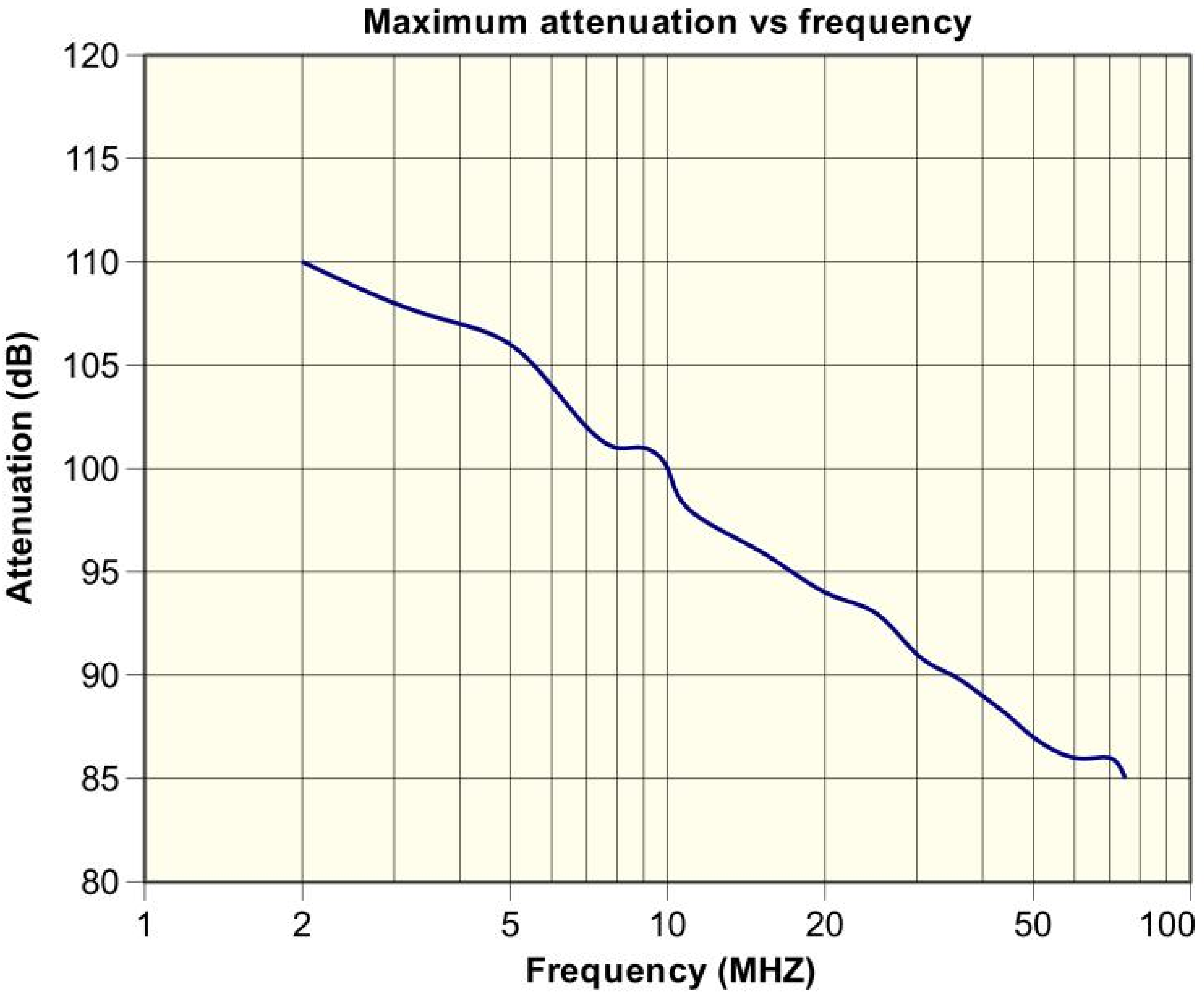


Fig.2: the actual attenuation for a selected value of 110dB between 2MHz and 75MHz. As the signal frequency increases, parasitic capacitances on the circuit board result in more of the input signal leaking through to the output.

A rotary encoder is used to adjust the amount of attenuation required, in either 1dB or 5dB steps, toggled by pressing the encoder's integral pushbutton switch. The firmware in the ATMega168 or ATMega328 microcontroller translates the attenuation to switch in the appropriate set of relays.

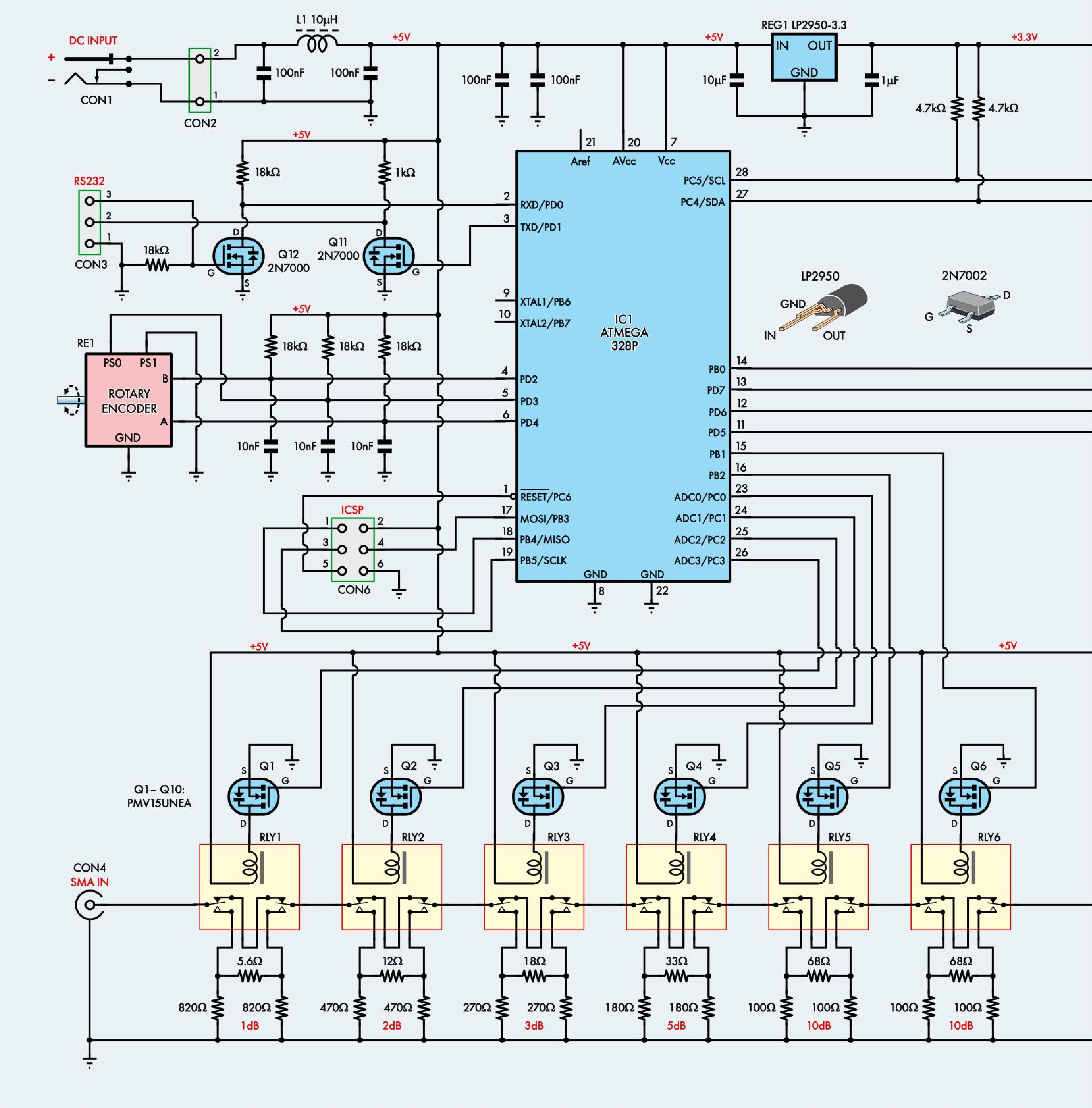
For example, to select 35dB, relays 3, 6 and 7 would be energised. To prevent relays chattering while the shaft encoder is turned, there is a short delay after the number is selected before the appropriate relays are turned on and off. Each relay's coil is switched using a small signal MOSFET.

You might have noticed that there are no diodes to absorb the back-EMF of the relay coils at switch-off. This is a bit unusual, but it does cut back on the number of components. This only works if the MOSFETs are rugged enough to withstand the voltage spikes caused by the relay coil magnetic fields dissipating. See the section below on 'Avalanche-rated MOSFETs' for more details on this.

As with my other designs, I have added a simplified RS-232 interface for debugging using MOSFETs Q11 and Q12. These may be omitted if you don't plan to use that interface.

The *Attenuator* is powered from a standard 5V DC mobile phone charger (or other USB power source). While this could be obtained from an

Fig.3: the entire circuit of the 110dB Attenuator. The main section consists of 10 switched attenuators, each made from three resistors, one relay (RLY1-10) and one MOSFET (Q1-Q10) to drive the relay. The transistors are driven by microcontroller IC1, which also monitors the rotary encoder and pushbutton, and communicates with the OLED to show the current attenuation setting.



DC INPUT
+
–
CON1
CON2
L1 10µH
100nF
100nF
+5V
100nF
100nF
+5V
REG1 LP2950-3.3
IN
OUT
GND
10µF
1µF
+3.3V
4.7kΩ
4.7kΩ
RS232
CON3
18kΩ
18kΩ
1kΩ
Q12 2N7000
Q11 2N7000
D
G
S
21
20
7
Aref
AVcc
Vcc
2
RXD/PD0
3
TXD/PD1
9
XTAL1/PB6
10
XTAL2/PB7
4
PD2
5
PD3
6
PD4
1
RESET/PC6
17
MOSI/PB3
18
PB4/MISO
19
PB5/SCLK
GND
8
GND
22
IC1 ATMEGA 328P
28
PC5/SCL
27
PC4/SDA
14
PB0
13
PB7
12
PB6
11
PD5
15
PB1
16
PB2
23
ADC0/PC0
24
ADC1/PC1
25
ADC2/PC2
26
ADC3/PC3
LP2950
GND
IN
OUT
2N7002
G
D
S
RE1
PS0
PS1
B
A
ROTARY ENCODER
GND
18kΩ
18kΩ
18kΩ
10nF
10nF
10nF
ICSP
CON6
1
2
3
4
5
6
+5V
+5V
+5V
Q1 – Q10: PMV15UNEA
Q1
Q2
Q3
Q4
Q5
Q6
RLY1
RLY2
RLY3
RLY4
RLY5
RLY6
CON4
SMA IN
5.6Ω
820Ω
820Ω
1dB
12Ω
470Ω
470Ω
2dB
18Ω
270Ω
270Ω
3dB
33Ω
180Ω
180Ω
5dB
68Ω
100Ω
100Ω
10dB
68Ω
100Ω
100Ω
10dB

output socket on the *Signal Generator*, I decided to use a separate supply to reduce potential RF leakage. You will note that the photos show an additional DC socket. This is for powering an external amplifier that was used for measurement.

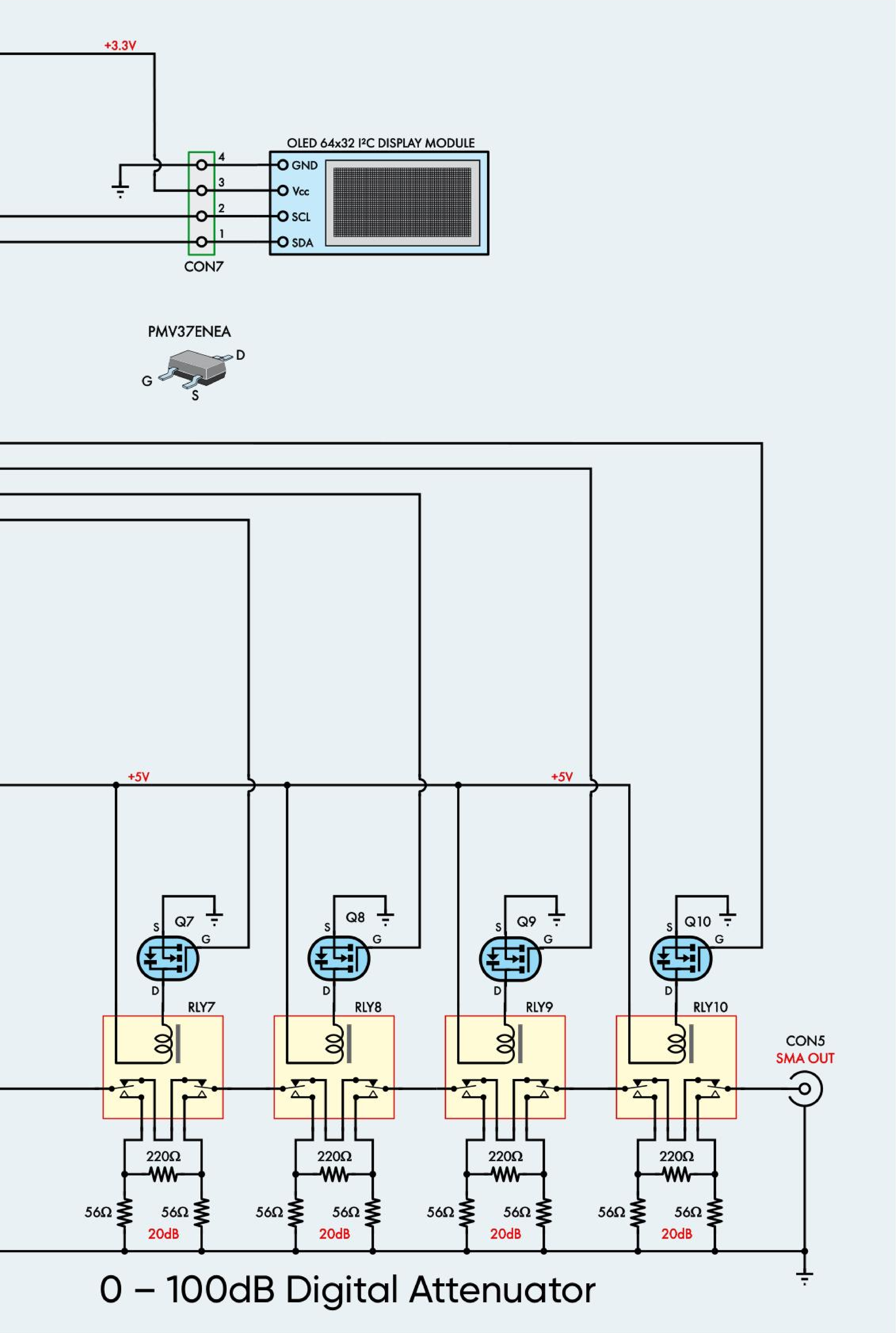
Inductor L1 is in series with the incoming supply to further reduce any outside RF. This seems to be effective, as powering it from a battery of three AA cells made no measurable difference in readings.

The same 0.96-inch SSD1306-based OLED screen is used to display the attenuation value as in the *Signal Generator*. A 3.3V regulator generates the OLED supply rail. The I^{2}C interface requires pull-up resistors to +3.3V. As the SDA and SCL outputs on PC4 and PC5 of IC1 are open drain, there is no problem with the 5V-powered micro interfacing with the OLED.

I chose NEC EC2-5NU relays. They are DPDT types with 5V-DC-rated coils. These are readily available and have good isolation. The measured capacitance between open contacts is 1pF, which does not sound like much. Still, the reactance at 75MHz is –j × 2122Ω, which is effectively in parallel with the 220Ω resistor in the 20dB sections, slightly reducing the attenuation.

The measured attenuation tracks the set attenuation fairly closely at 2MHz and below, as shown in Fig.1. I took these readings with the tinySA spectrum analyser. The noise floor of the tinySA is about –90dBm, so I used a 30dB low-noise amplifier (LNA) to measure down to –110dBm. The measured value varied slightly on each pass, so I averaged several readings.

Once the frequency gets above 2MHz, the accuracy drops off, and Fig.2 shows the maximum attenuation achievable up to 75MHz. To get a lower signal level at the higher frequencies, you will need to put a fixed 30dB attenuator on the unit's output.



0 – 100dB Digital Attenuator

Avalanche-rated MOSFETs

Avalanche-rated MOSFETs (such as those specified in the parts list) must be used to ensure longevity. This is easy to check by searching the device data sheet for the avalanche energy rating (usually expressed in mJ).

When a MOSFET's drain-source rating voltage is exceeded, it can enter avalanche breakdown, similar to a zener diode. In this mode, the channel conducts current until the voltage drops.

The problem with this is that a typical MOSFET is made of many (usually thousands of) cells, and there's no guarantee that each cell will break down at the same voltage. That means the energy may pass through a very small proportion of the MOSFET area, causing intense local heating and possibly failure.

Also, the avalanche current is not conducted through the normal channel but rather through a 'parasitic bipolar transistor' formed by two semiconductor junctions within the MOSFET. This also has the effect of concentrating the current into a smaller area than usual.

Avalanche-rated MOSFETs solve this by two methods. First, they are designed and manufactured in such a way to minimise the variation in breakdown voltages between individual cells so that the current is spread out.

Second, after being manufactured, they are tested by being forced into avalanche breakdown with a pulse of energy at least as high as specified in the data sheet. Any 'weak' devices that cannot handle this fail and are discarded. Only the survivors go on to be sold.

We've calculated the energy pulse from the relay coils in this design at around 1mJ. The MOSFETs we have specified have single-pulse ratings of around 15mJ. They only need to handle one pulse every few seconds, so this should be well within their capabilities.

If substituting MOSFETs, opt for a minimum avalanche rating of 10mJ.

For more information about this topic, see the excellent PDF from Infineon at: **https://bit.ly/pe-aug23-inf**

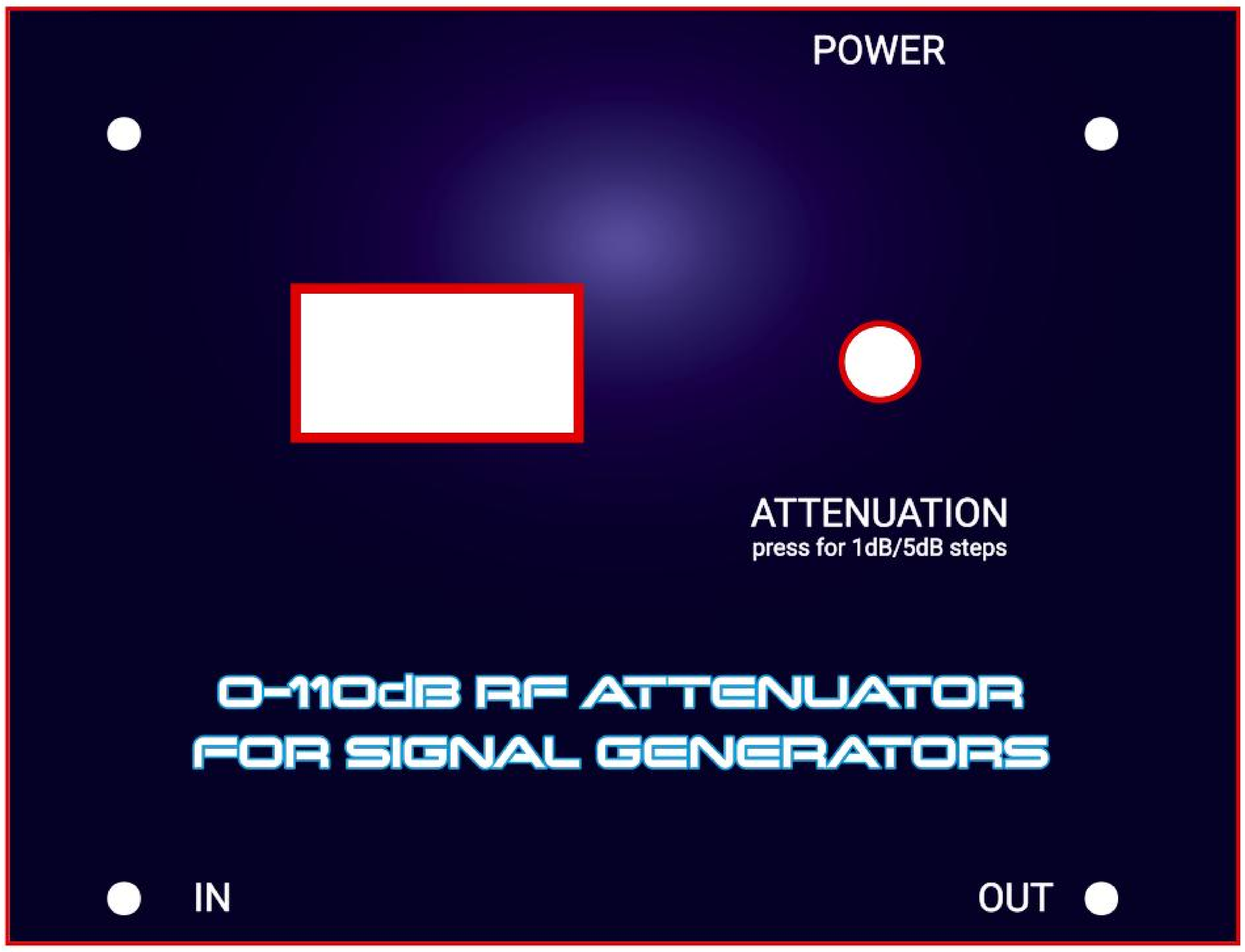


Fig.4: the front panel label for the Attenuator. The number and size of cutouts have been minimised to prevent RF leakage into or out of the case.

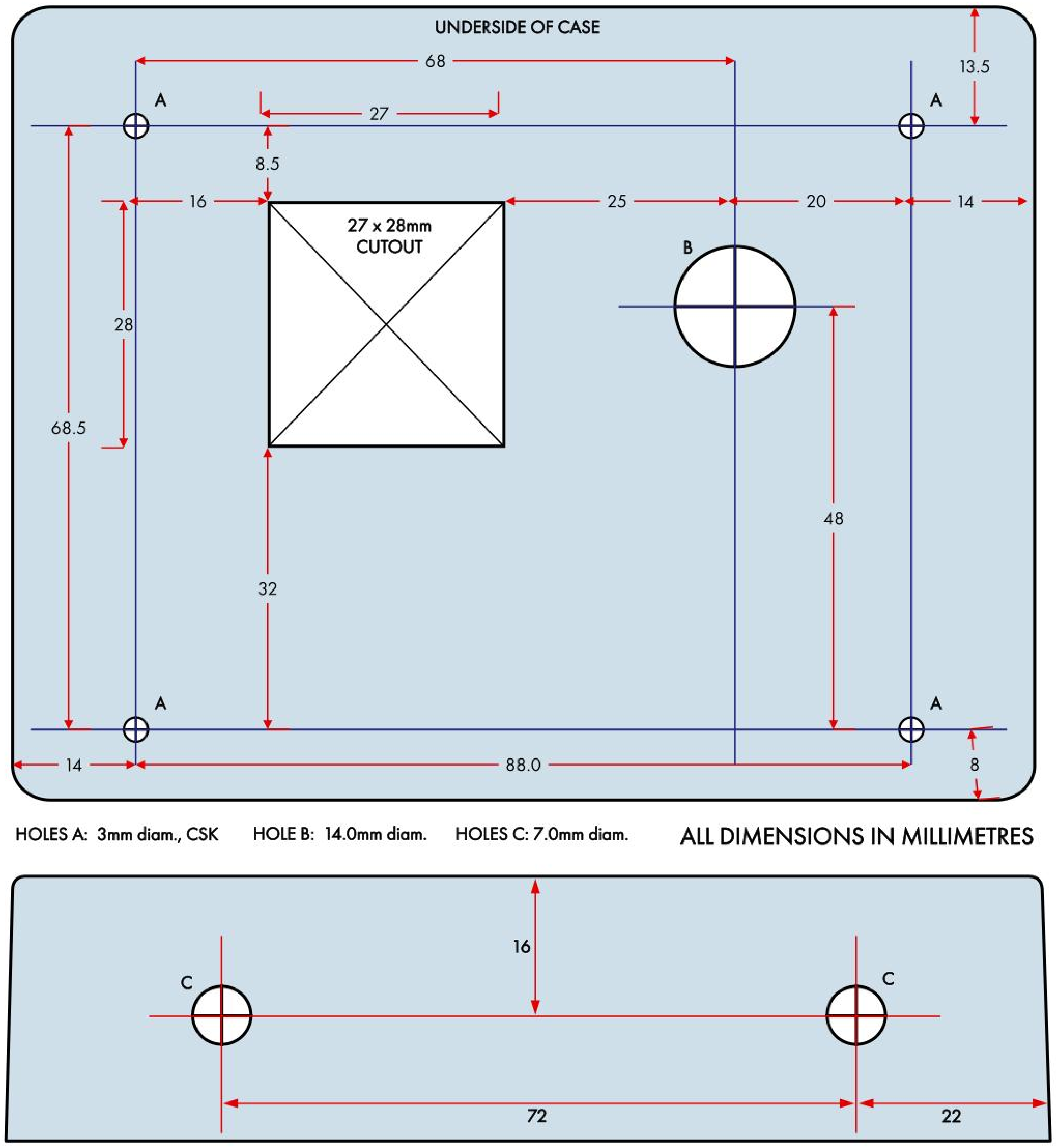


Fig.5: luckily, there aren't too many holes that need to be cut in the diecast case. They can all be drilled, except for the rectangular hole for the OLED. There are various ways to make that; just be sure to do it slowly to avoid it becoming jagged or oversized.

Construction

The unit is built into a standard aluminium diecast box, available from Jaycar and Altronics (the same one used for the recently-described *AM/FM Signal Generator*). It's best to prepare this before assembling the PCB. I sprayed mine black to improve its appearance.

I printed the *Attenuator's* label (Fig.4) on to photographic paper and added a 1.5mm-thick protective clear polycarbonate sheet on top – cut to the same size as the label. You can download this artwork from the August 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

The PCB attaches to the inside of the case using 12mm threaded spacers. If you can't get these, use 10mm threaded spacers with an added nut to extend them to 12mm. I also sprayed the screws through the front panel black to improve the overall appearance.

The required cutouts in the enclosure are shown in Fig.5. For best accuracy, locate the reference point in the bottom left and drill this to 3mm diameter. Then attach the blank PCB to use as a template. Square it up, drill the opposite corner and secure it with another screw. Now drill the other mounting holes.

The encoder location on the PCB has a small hole in the centre on the PCB. Drill the panel through this using a 1.5mm-diameter drill bit, then drill holes in the case corresponding to the four OLED mounting holes to 2.5mm.

Remove the PCB and enlarge the hole for the shaft encoder to 14mm diameter. It needs to be that large so that the PCB can be manoeuvred into position. Increase the size of the OLED mounting holes to 4mm and use the outside of these to mark the cutout needed.

How you make the cutout depends on the equipment and skills that you have. Perhaps the simplest approach is to drill a series of reasonably small (say 3-4mm) holes around the *inside* of the perimeter. Join these with a file until the centre part drops out, then use a larger flat file to smooth the edges until they are straight and the hole is just large enough.

Finally, drill two 7mm holes for the SMA connectors on the front and a hole for the DC connector on the back. There is not much room for this connector; it should be 7mm up from the bottom of the case. I also placed a small toggle switch next to the DC connector for the power, but that is optional.

PCB assembly

Most of the components mount on a double-sided PCB coded CSE211003 that measures 76 x 95.5mm and is available from the *PE PCB Service*. Fig.6 shows where the parts go.

The resistors and capacitors are mostly SMD M2012/0805 or

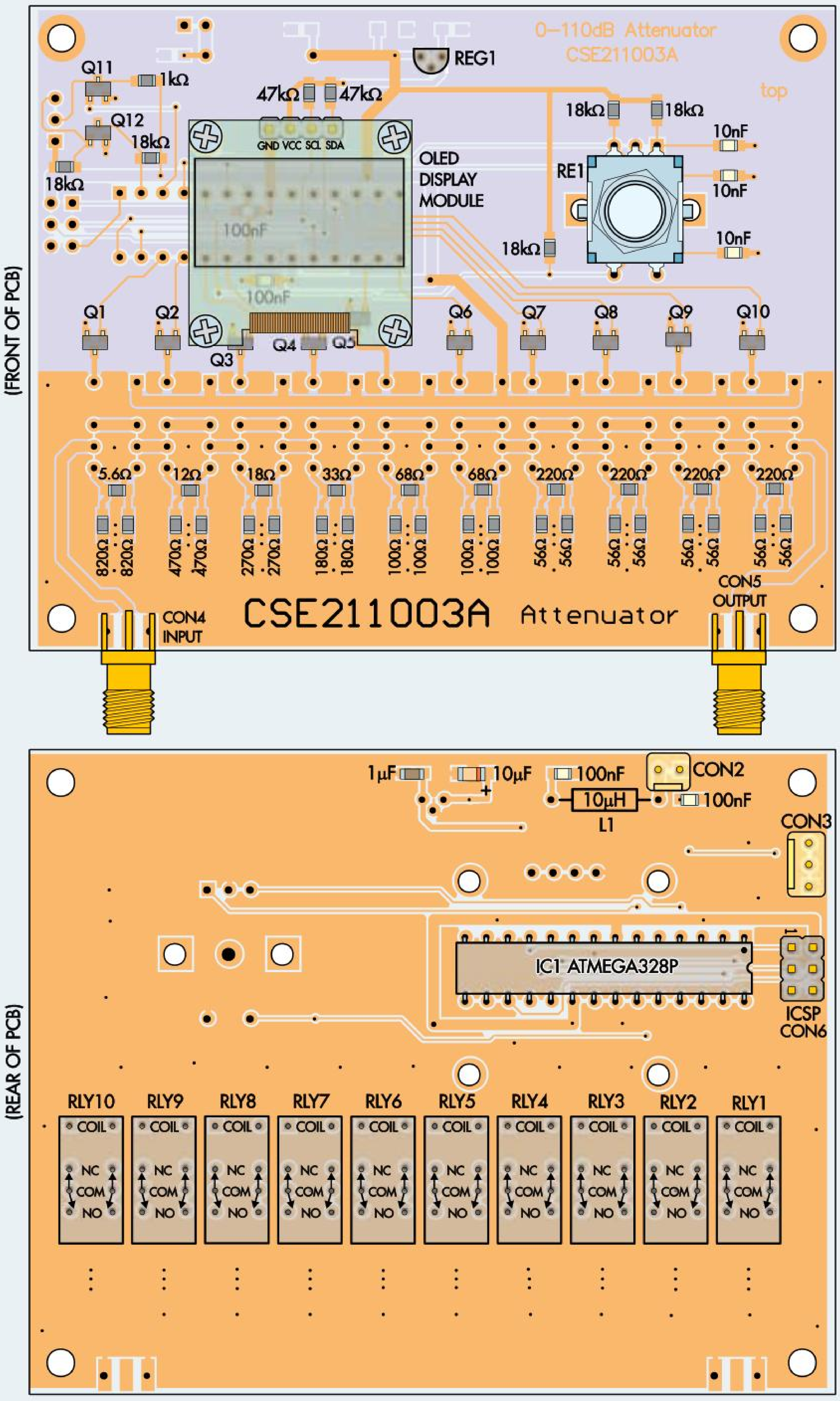

0–110dB Attenuator
CSE211003A
top
Q11
1kΩ
Q12
18kΩ
18kΩ
47kΩ
47kΩ
GND VCC SCL SDA
REG1
18kΩ
18kΩ
10nF
RE1
10nF
10nF
18kΩ
OLED DISPLAY MODULE
100nF
100nF
(FRONT OF PCB)
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
5.6Ω
12Ω
18Ω
33Ω
68Ω
68Ω
220Ω
220Ω
220Ω
220Ω
820Ω 820Ω
470Ω 470Ω
270Ω 270Ω
180Ω 180Ω
100Ω 100Ω
100Ω 100Ω
56Ω 56Ω
56Ω 56Ω
56Ω 56Ω
56Ω 56Ω
CON4 INPUT
CSE211003A Attenuator
CON5 OUTPUT
1µF
10µF
+
100nF
CON2
10µH
L1
100nF
CON3
IC1 ATMEGA328P
ICSP CON6
(REAR OF PCB)
RLY10
RLY9
RLY8
RLY7
RLY6
RLY5
RLY4
RLY3
RLY2
RLY1
COIL
NC
COM
NO

Fig.6: the resistors, capacitors and MOSFETs all come in SMD packages but are pretty easy to solder. The micro, regulator, relays, headers and rotary encoder are through-hole parts. Fit all the SMDs first, then the through-hole parts from lowest profile to tallest, with the edge connectors last. Be careful to orient the microcontroller and regulator as shown.

M3216/1206 size, while the transistors are in SOT-23 packages. Solder all the SMDs first, followed by the through-hole components, then the SMA connectors, and the rotary encoder last.

There are options for other 3.3V regulators if the LP2950-3.3 regulator is not available. Some have different pinouts, so check this if substituting. If your replacement regulator has a reversed pinout, you can mount it on the opposite side of the board.

The OLED screen plugs into a 4-pin socket strip. Although four mounting holes are provided, attaching it with two screws and two 10mm spacers is adequate.

The holes in the OLED may be either 2mm or 2.5mm, so use either M2 x 16mm or M2.5 x 16mm machine screws and nuts.

Using it

It's about as easy as it gets. Simply power the unit up, use the rotary encoder to dial in the amount of attenuation required while checking the screen display, then ensure your input and output cables are connected to the correct sockets. Remember that pushing down on the rotary encoder knob switches between adjustment steps of 1dB and 5dB.

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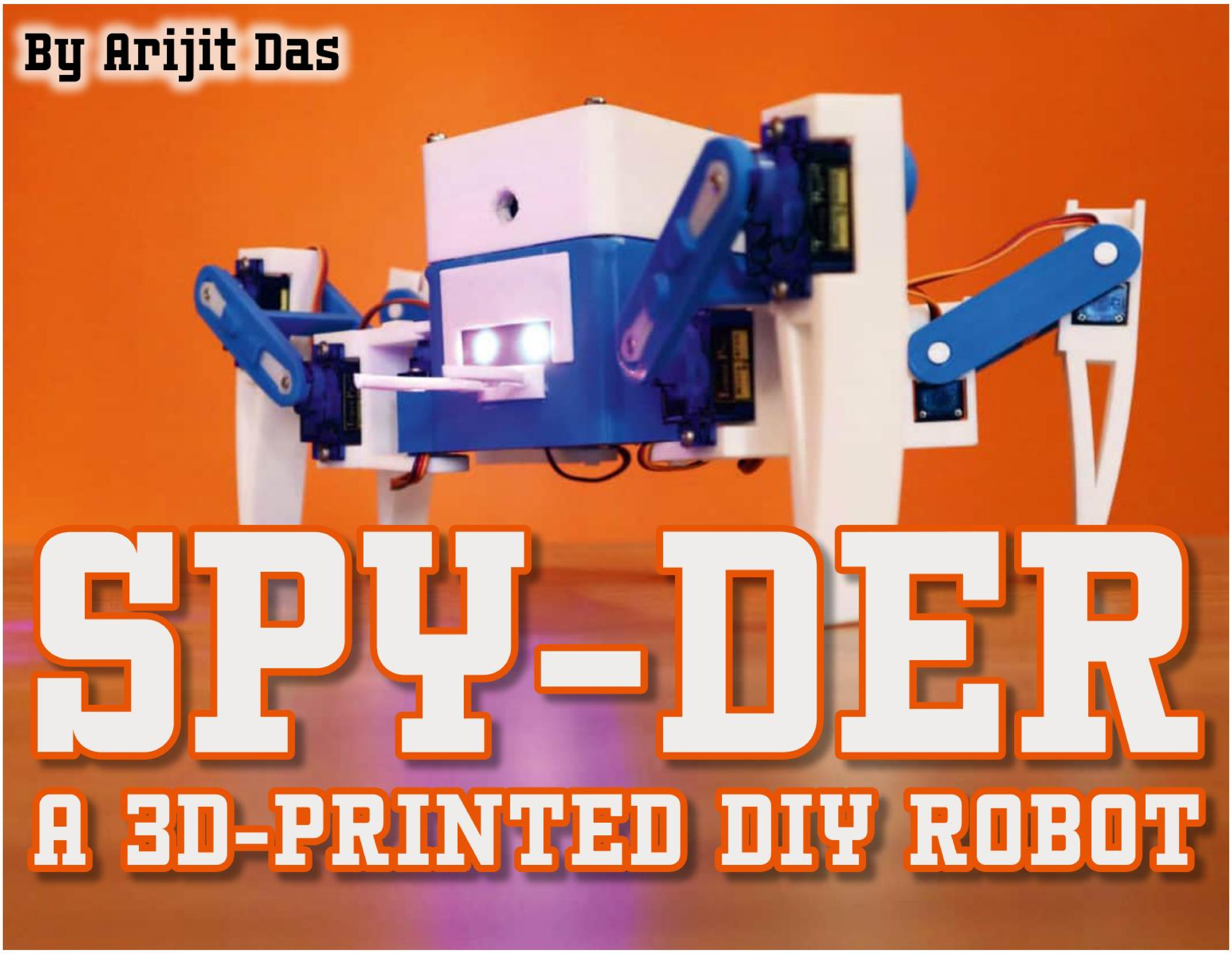
By Arijit Das



SPY-DER

A 3D-PRINTED DIY ROBOT

SPY-DER is a speech and web-controlled surveillance spider robot. It walks like a spider and acts as a spy using its camera, hence the name 'SPY-DER'. The best aspect of it is that you can make it yourself using some 3D-printed parts, a bunch of servos and some low-cost off-the-shelf electronic modules.

You can control this robot in two ways — using voice commands or its web-based control interface. For example, I have nicknamed mine 'Bumblebee'. Whenever I call it by that name, it starts listening to me, and it will then act on voice commands. I am using two main technologies to enable this: hot-word or wake-word detection and speech recognition.

The speech recognition also involves intent detection, so that I can give it the same command in different ways. For example, if I say 'wave your hands' or 'say hello', either way, it will wave its legs.

For the web-control part, one can simply open a particular URL in any browser and use it to control the SPY-DER. The web-based interface contains all the control options as buttons. You can open another URL to watch the live video feed from this robot's camera.

You can see a short demonstration video that shows what SPY-DER can do at **https://youtu.be/3edXTxIZ_2U**

Developing SPY-DER

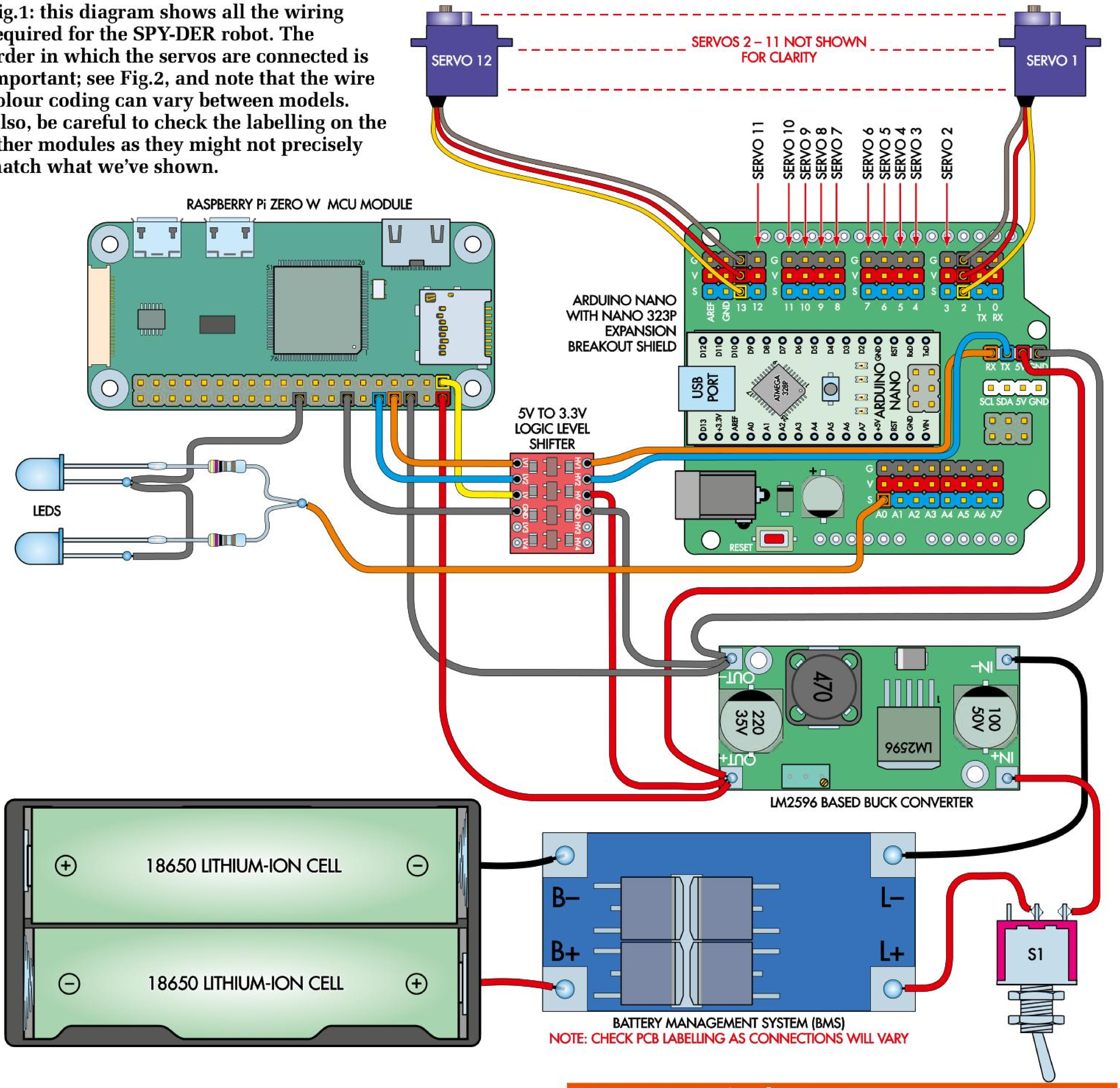
Initially, I built a simple Bluetooth-controlled spider robot using an Arduino Nano, but it could only be controlled using an Android or iOS app. Thus, I added speech recognition, web control and surveillance features.

Implementing all these features using an Arduino was impossible – what I needed was a small computer. That's why I decided to add the Raspberry Pi Zero. In theory, the whole system could have been implemented using just the Raspberry Pi Zero, but it would have been too time-consuming to rewrite all the spider movement control code.

So I decided to keep the Arduino and add the Raspberry Pi and have them communicate over a serial link. The Arduino controls all the spider's movements while the Raspberry Pi sends commands to the Arduino. This also means that I don't have to worry about the Raspberry Pi being so busy doing speech recognition that it loses control of the limbs!

All the Raspberry Pi code is written in Python. For the web-based control part, I used the Flask framework and built the web page using HTML, CSS and jQuery. For the live video streaming, I used RPi-Cam-Web-Interface (see **https://elinux.org/RPi-Cam-Web-Interface**) because it has very low latency.

Fig.1: this diagram shows all the wiring required for the SPY-DER robot. The order in which the servos are connected is important; see Fig.2, and note that the wire colour coding can vary between models. Also, be careful to check the labelling on the other modules as they might not precisely match what we've shown.


SERVO 12
SERVO 1
SERVOS 2 – 11 NOT SHOWN FOR CLARITY
SERVO 11
SERVO 10
SERVO 9
SERVO 8
SERVO 7
SERVO 6
SERVO 5
SERVO 4
SERVO 3
SERVO 2
RASPBERRY Pi ZERO W MCU MODULE
ARDUINO NANO WITH NANO 323P EXPANSION BREAKOUT SHIELD
USB PORT
ARDUINO NANO
ATMEGA 328P
AREF GND 13 12 11 10 9 8 7 6 5 4 3 2 1 0 TX RX
RX TX 5V GND
SCL SDA 5V GND
A0 A1 A2 A3 A4 A5 A6 A7
RESET
5V TO 3.3V LOGIC LEVEL SHIFTER
LEDS
470
220 35V
100 50V
LM2596
OUT– OUT+ IN– IN+
LM2596 BASED BUCK CONVERTER
18650 LITHIUM-ION CELL
18650 LITHIUM-ION CELL
B– B+ L– L+
S1
BATTERY MANAGEMENT SYSTEM (BMS)
NOTE: CHECK PCB LABELLING AS CONNECTIONS WILL VARY

For speech recognition and hot word detection I used Picovoice (**https://picovoice.ai/**) and modified the code in Python. I tried local speech recognition, but the RAM and processing power of the Raspberry Pi Zero is limited, so the accuracy was not that good, and the latency was also high.

The physical robots parts are based on an existing robot that I found at **thingiverse.com/thing:2901132** (but it has since been removed).

I redesigned some parts in TinkerCAD (**www.tinkercad.com**) and made all of the relevant parts available online here: **thingiverse.com/thing:4815137**

I 3D-printed all of the parts using an Ender 3 3D printer (see Photos 1 and 2).

Starting assembly

If you'd like to watch a video, I have made one (just over one hour long) going over the project in detail at: **https://youtu.be/KkZiZggtvIU**

It is definitely worth watching before you start assembly. And do see the parts list later in the article for what you will need to build the SPY-DER.

I have created another video just under 30 minutes long that concentrates on the steps for building SPY-DER, which you can view at **https://youtu.be/fnMmnd9k6q8**

Step 1 – 3D print the parts

First, if you haven't already done so, print all the 3D parts that make up the robot. The STL files are available for download from the August 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

Step 2 – attach the servo motors

Next, you need to attach the twelve SG90 servo motors using M2 screws, as shown in Photos 3 and 4. Four of the 12 servo motors connect to the body while the other eight connect to the legs. Attach them with screws, but don't add the 'horns' yet.

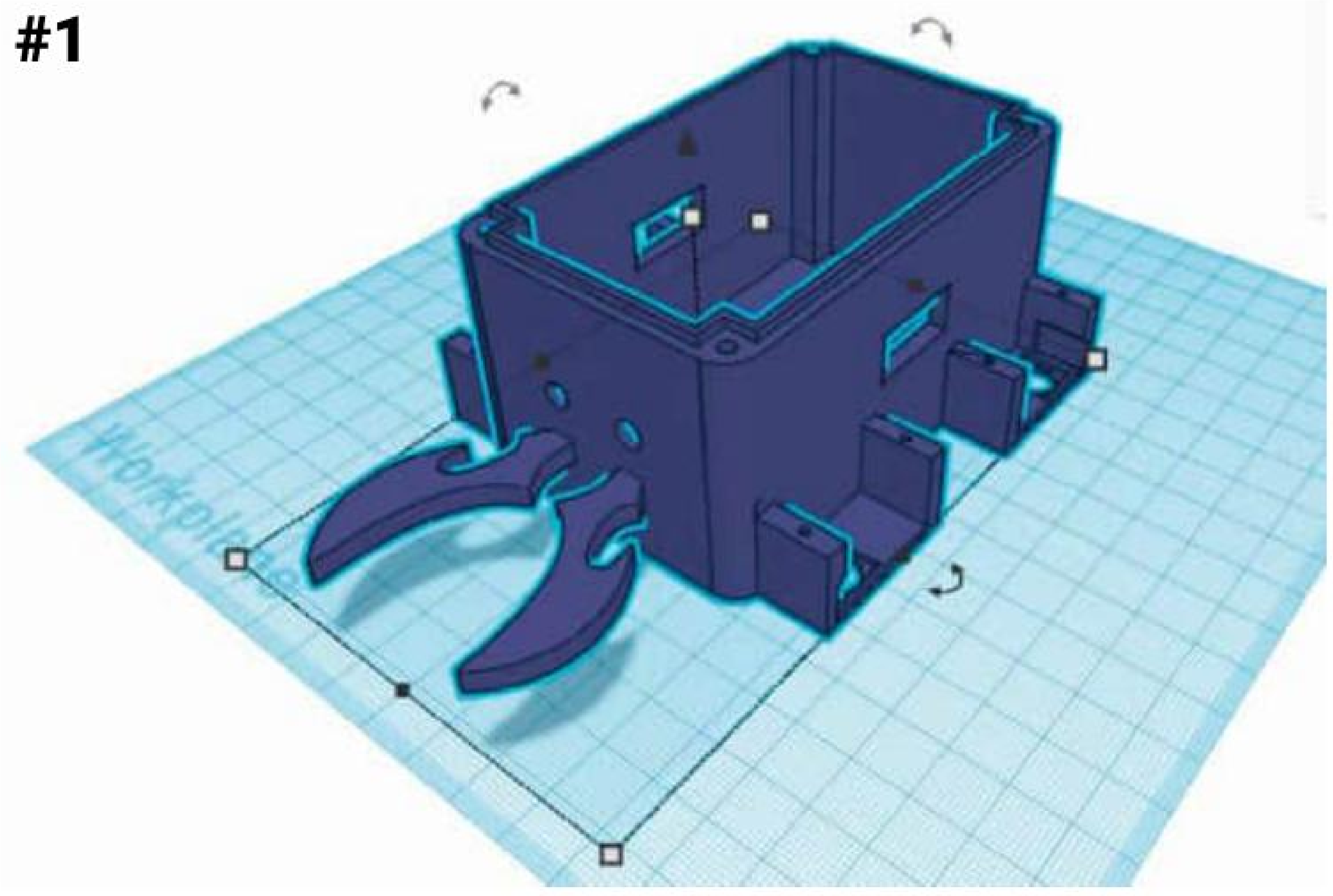
Plastic gear servo motors are used for this project as the robot is pretty light. I have provided some useful details on attaching the servos, along with Steps 3, 4, 5 and 6, in the video at: **https://youtu.be/fnMmnd9k6q8**

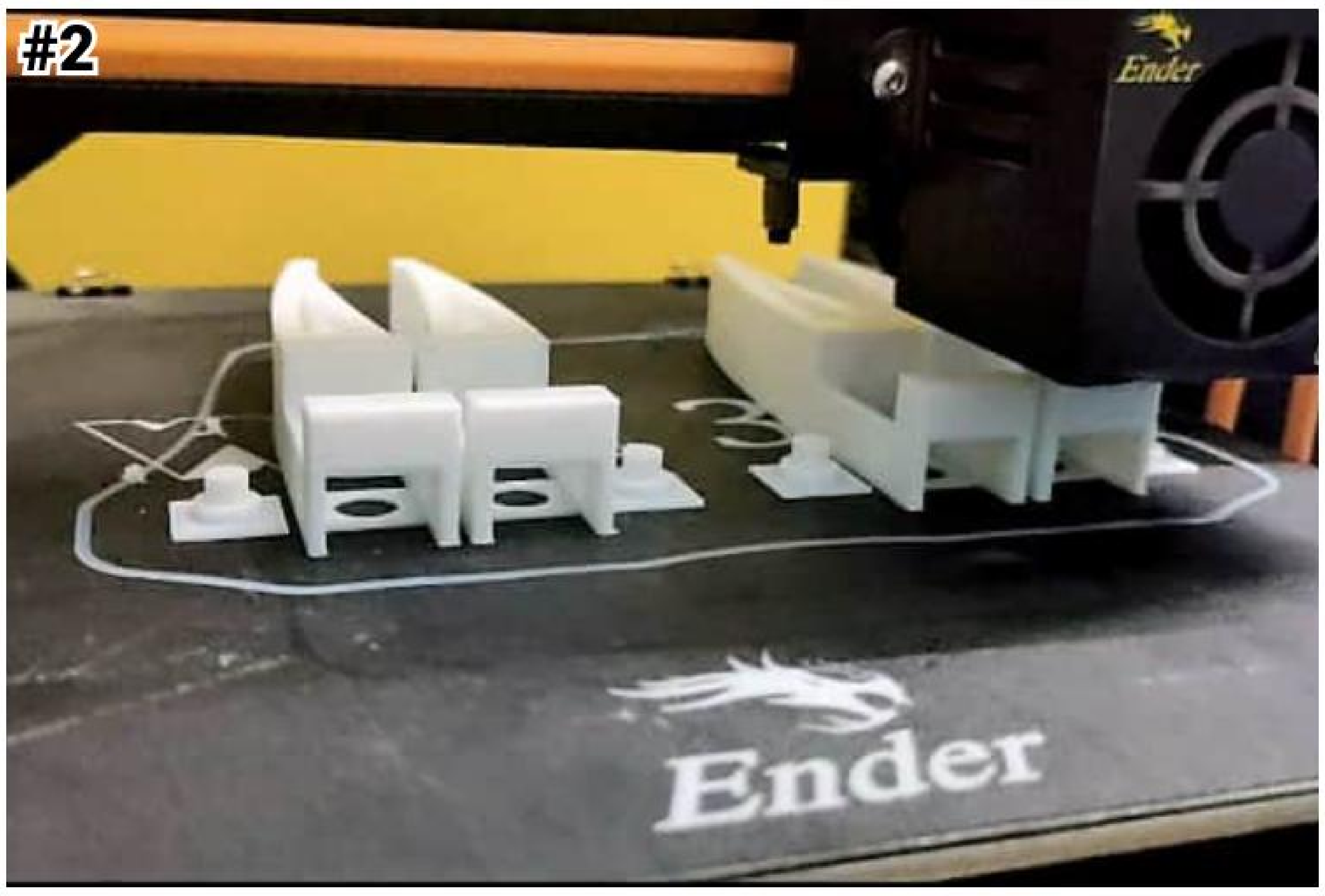
Step 3 – join the body parts

Next, connect all the 3D-printed body parts through the servo motors – see Fig.2. Don't attach the horns just yet.

Step 4 – connect the battery and BMS

The power requirements of the 12 servo motors is quite high, so I used two 18650 Li-ion cells in series. The Arduino, servo


#1


#2

motors and Raspberry Pi use a 5V DC supply. An LM2596 buck converter is used to convert the 7-8V output of the battery to a regulated 5V, which is then fed to all the components. For safety, a battery management system (BMS) is used.

Fig.1 shows how these parts are connected, including some other parts we'll get to shortly.

Make sure that when you join these, it can still fit within the robot's body, as inserting it is the next step. Photo 5 shows how I wired these parts up (including the on/off toggle switch), while Photo 6 shows it installed in the robot body. Note how the servo power/control leads have been fed into the main cavity.

Step 5 – setting up the Arduino

First, plug the Arduino Nano into the socket on the Prototype Shield – make sure it's the right way around. Next, plug all the servo motors into the headers on the I/O shield. While attaching the servo motors, make sure you have attached them according to the numbering shown in Fig.1 and Fig.2, with the black wires to the side marked 'G' (for ground).

The I/O shield also needs to be wired up to the power supply which powers the servo motors and the Arduino. Make sure the power switch is off when you connect it.

Photo 7 shows what the Nano looks like once placed inside the robot's body.

Step 6 – servo calibration

Now, upload the code to the Arduino Nano. The code is available to download from **https://bit.ly/pe-aug23-spy4** – it's also available from the August 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

The first step is to calibrate the robot legs. The program to do this is in the 'Legs' folder (**legs.ino**). Before calibrating the servo motors, check the connections are correct and appropriately powered. After running the **legs.ino** calibration sketch, screw the horns that hold the legs to the body.

Step 7 – initial functional testing

To check the basic functionality of the robot, there is another Sketch named **program1.ino** in the program1 folder of the GitHub repository. After uploading this, when you power the robot up, it will automatically start testing all the features in the following order:

- Stand up
- Move forward
- Move backwards
- Move left
- Move right
- Hand wave
- Dance

Any deviations from the above movements need to be checked as they suggest an incorrect connection or component that is not working correctly. To know more about this and the last step, do watch my videos.

Step 8 – uploading the final Arduino code

Now you can upload the final code to the Arduino. This will work with the Raspberry Pi. Lke the The code is available from **https://bit.ly/pe-aug23-spy5** (and the *PE* website). Upload the **SPY-DER_Arduino.ino** file to the Arduino. This program takes commands from the Pi and acts accordingly.

Step 9 – preparing the Raspberry Pi

Start by installing the latest version of the Raspbian operating system on the Raspberry Pi. You can use SSH or a direct HDMI connection while working with the Raspberry Pi.

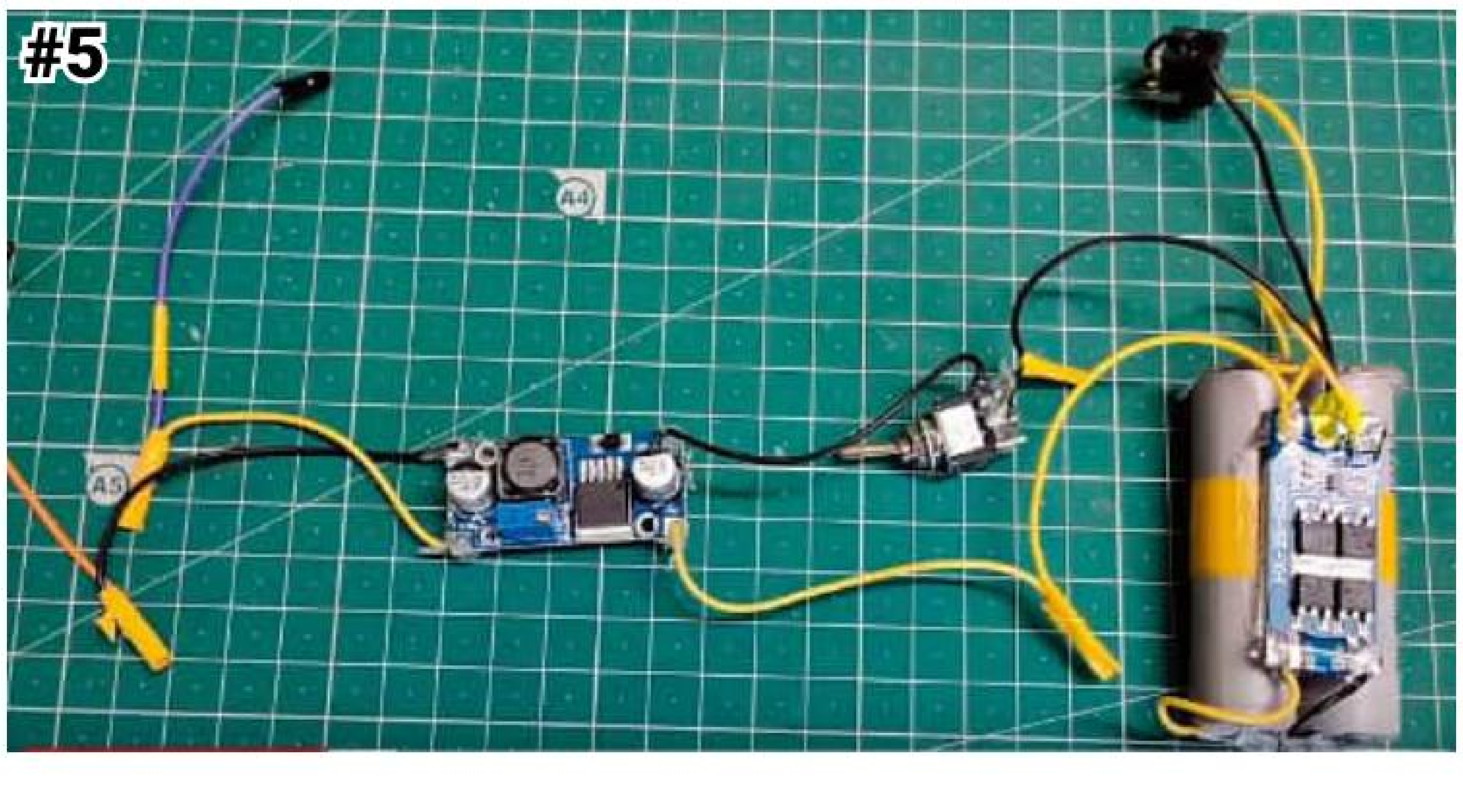
Step 10 – Raspberry Pi microphone and camera

The Raspberry Pi needs to have the mic, camera and logic level shifter attached, as shown in Photo 8.

This logic level shifter is needed to interface the 5V Arduino with the 3.3V I/Os on the Raspberry Pi. The Arduino connects to the 5V ('HV') side of the level shifter, while the Pi goes to the 3.3V ('LV') side.

I have a general video about using a level shifter like this for serial communication between different boards at: **https://youtu.be/e04br5J4UpQ**

To connect a microphone to the Raspberry Pi Zero, there are three options: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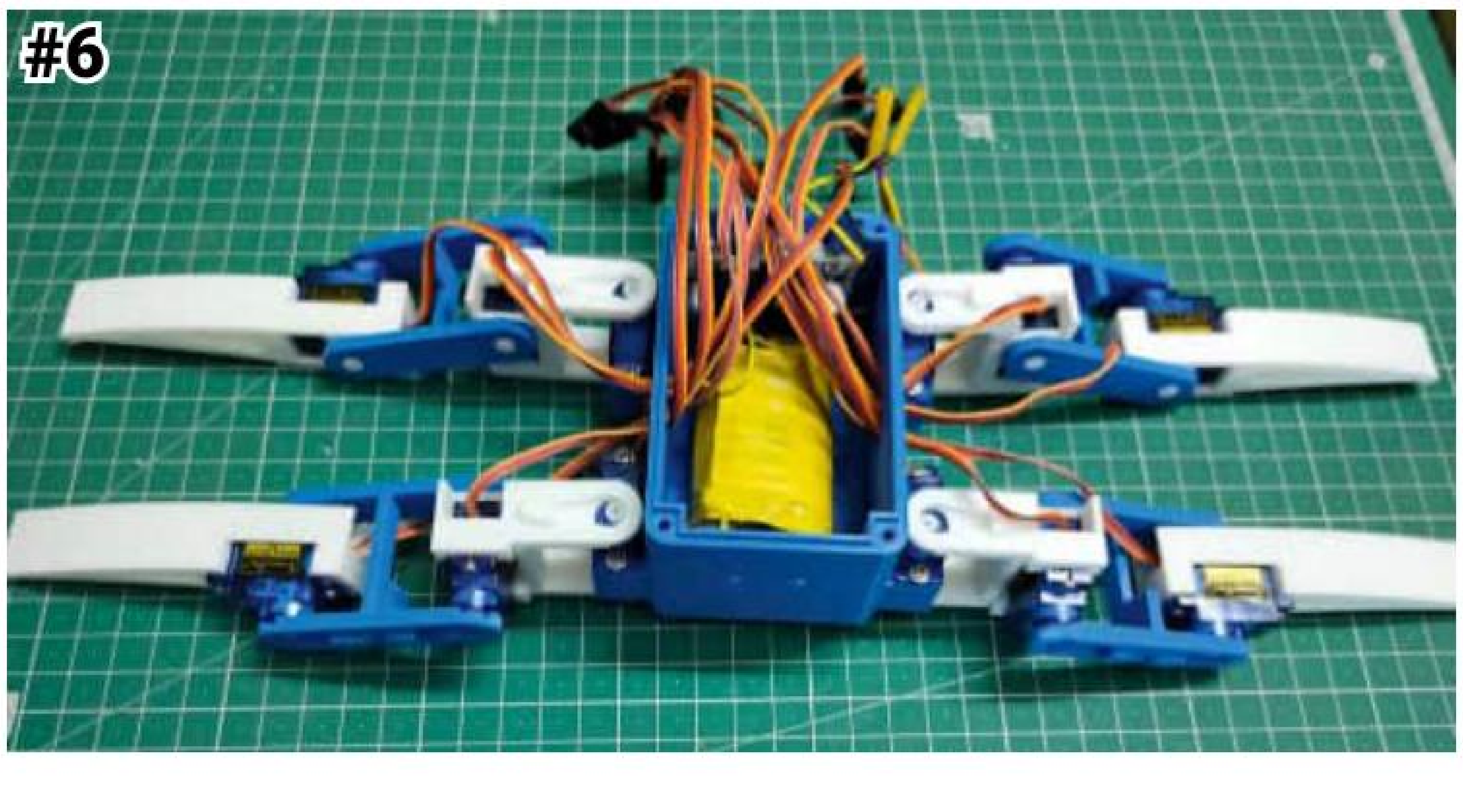
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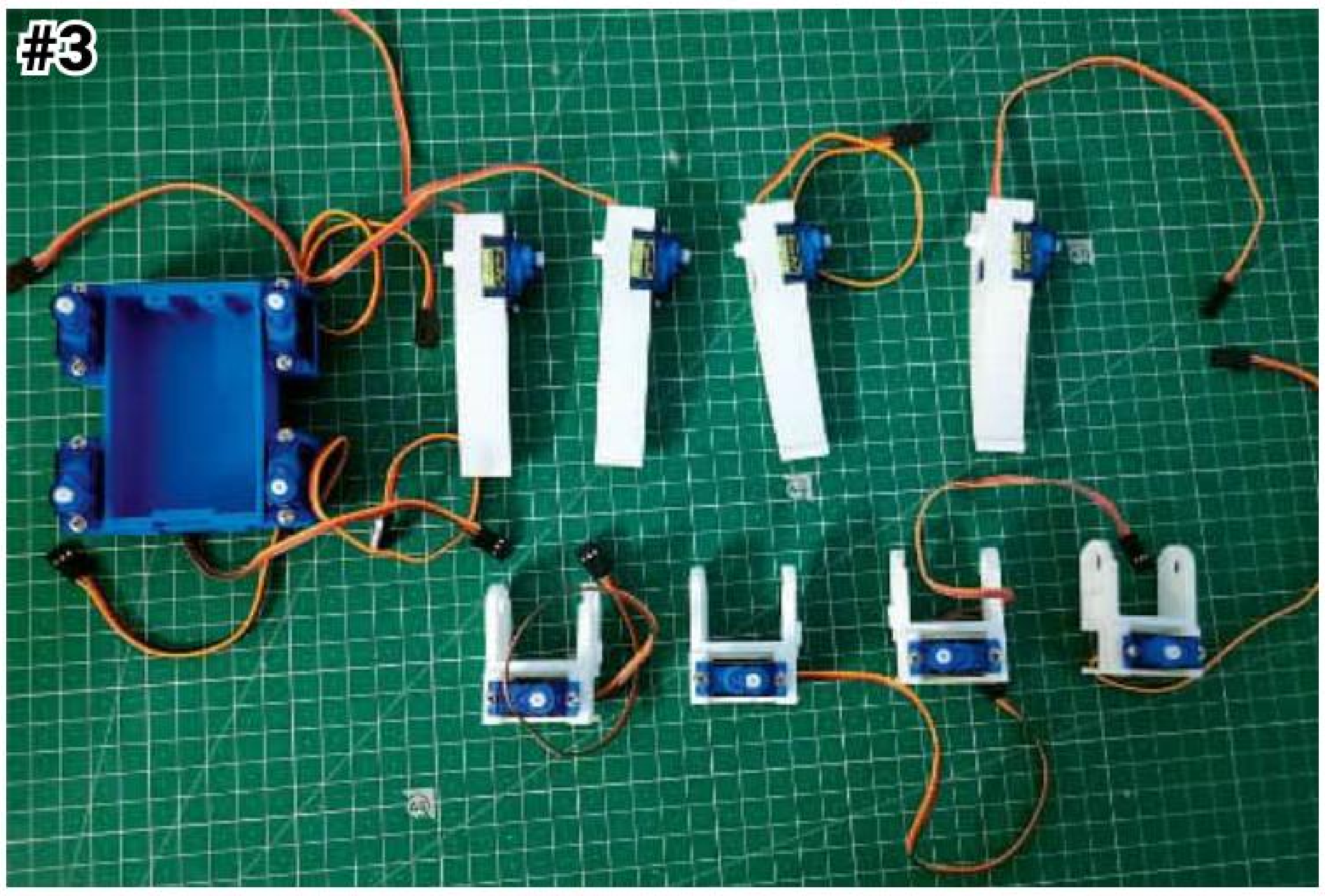
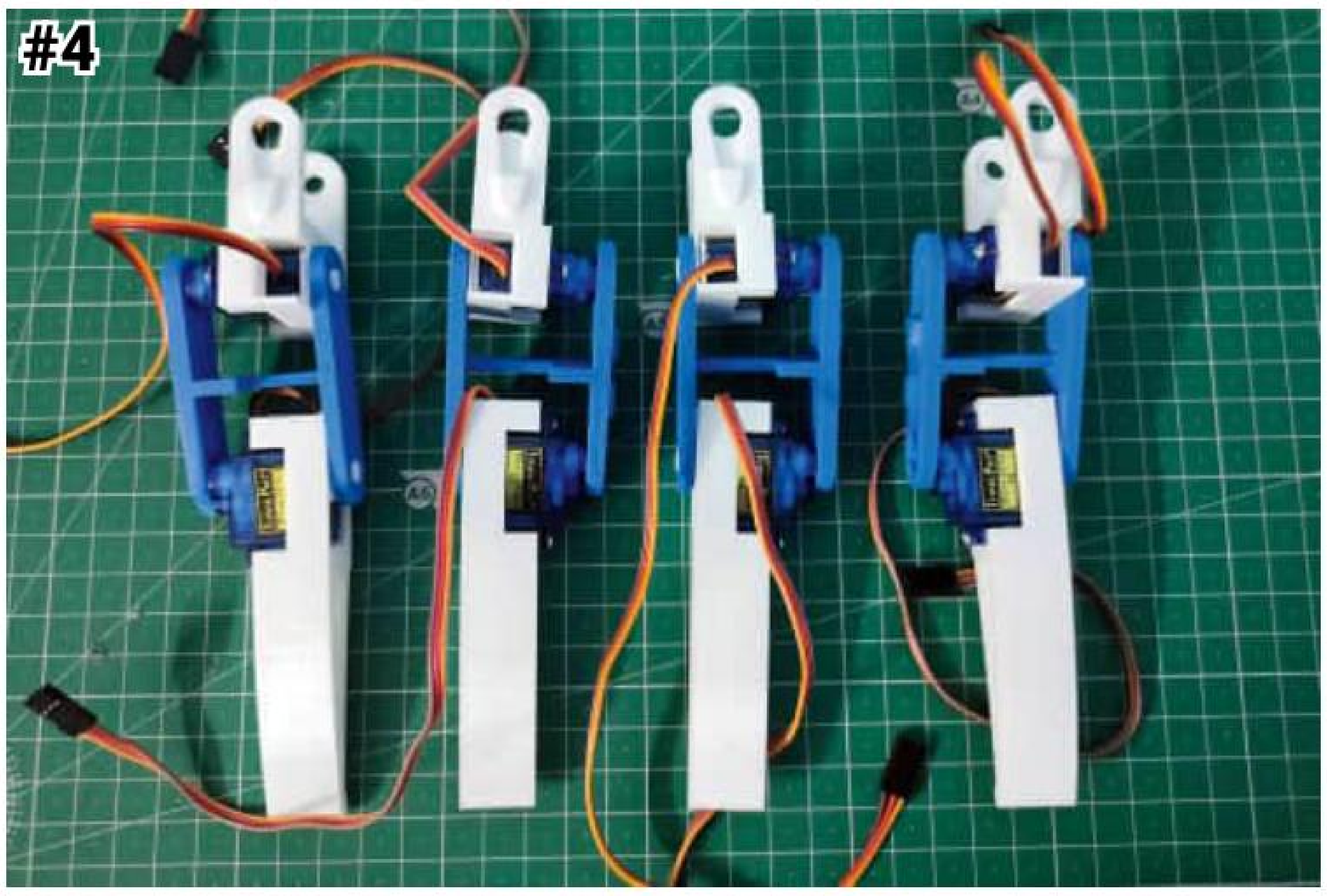




1. Connecting a USB microphone using an OTG cable
2. Connect a microphone with a 3.5mm jack plug using a Raspberry Pi sound card and OTG cable
3. Using a Raspberry Pi audio hat.

I suggest you connect a USB microphone using an OTG cable as I did. The Raspberry Pi supports most standard USB microphones.

For the camera, use a standard Raspberry Pi camera – **www.raspberrypi.com/products/camera-module-v2** – and plug it in as per the instructions. I have a video on using the Raspberry Pi Camera with a Raspberry Pi Zero at: **https://youtu.be/oo0A_yRrIxQ**

Step 11 – setting up the Raspberry Pi

The remaining setup steps are as follows:

1. Set up VNC Connect on the Raspberry Pi so that you can remotely access and control it from your computer.
2. Switch on the camera in the settings or use raspi-config from the command line. Check that the camera works; RaspiStill can be used to test it.
3. Enable the microphone and then test recording from the terminal. You might need to modify the **.asoundrc** file to set up the mic.
4. Test serial communications between the Pi and Arduino.

Clone all the code from my GitHub repo (see: **https://bit.ly/pe-aug23-spy1**) onto the Raspberry Pi (say, into the home folder).

Clone the Picovoice (**https://picovoice.ai/**) repository from **https://github.com/Picovoice/picovoice** and then launch the Picovoice program in my GitHub repository (see the README file).

Install RPi-Cam-Interface for video streaming. You can get it from: **https://elinux.org/RPi-Cam-Web-Interface** and see the video at: **https://youtu.be/yzpqEw1kEGo** for more details.

Train the Rhino speech-to-intent model so that for a single task, you can use different commands; Rhino is contained in the Picovoice repository.

To train the model, open a web browser and then go to: **https://console.picovoice.ai/rhn** and input different kinds of commands and their intentions – see Screen 1. Depending on the intentions you use here, you need to change the **picovoice_demo_mic.py** file.

After writing down all the commands and intents, follow the prompts on the webpage to train the model by using the microphone, then upload the trained model to the Raspberry Pi.

For web control, you need to install the Flask framework in Python; all of the Python and HTML files are in my repository.

Step 12 – finishing the build and controlling the robot

Fit everything inside the body (Photo 9) and glue the microphone and camera into the holes provided in the lid (Photo 10). Attach the lid, power it up and then use VNC to connect to the Raspberry Pi wirelessly from your computer. Photo 11 shows the completed robot with the lid attached.

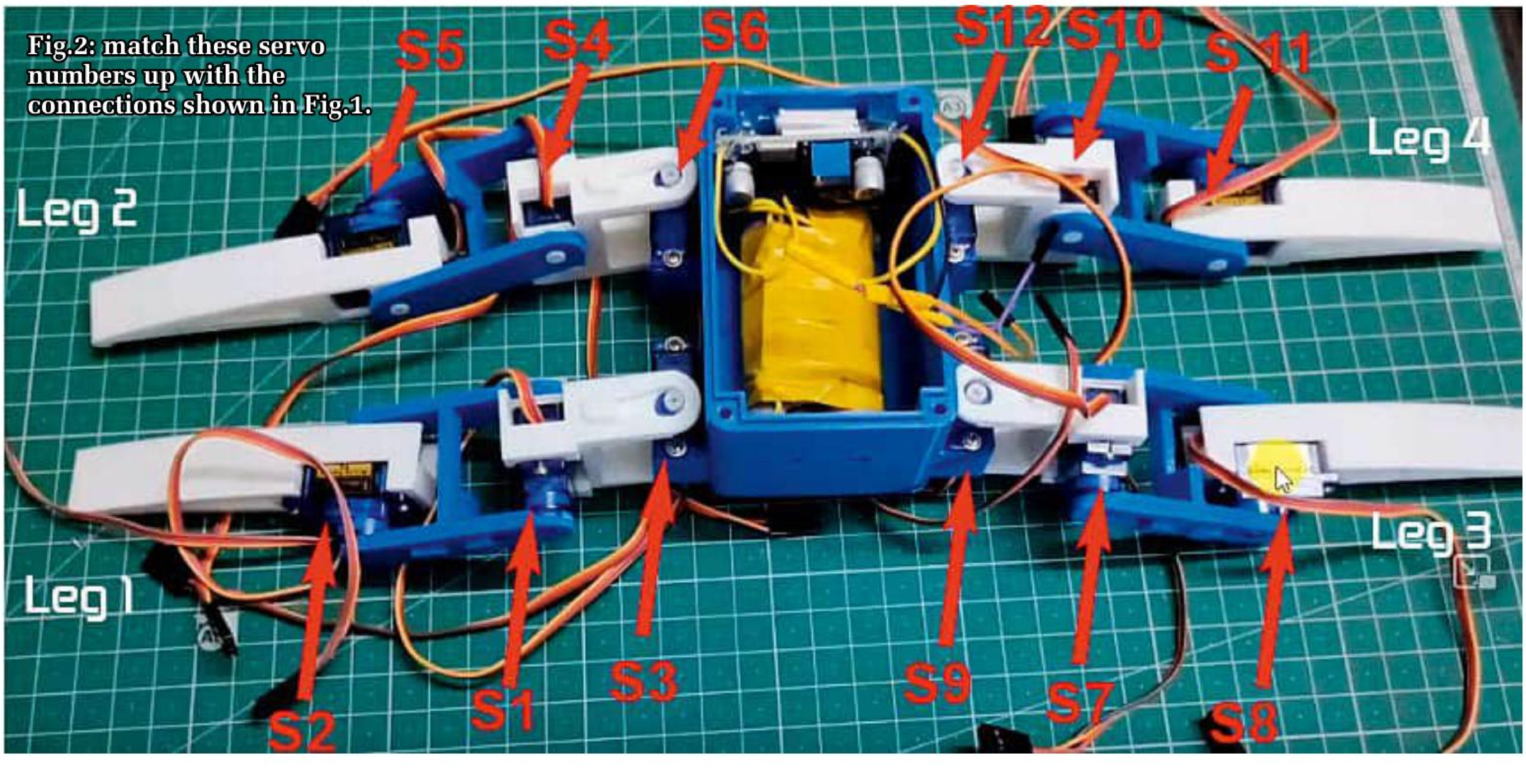
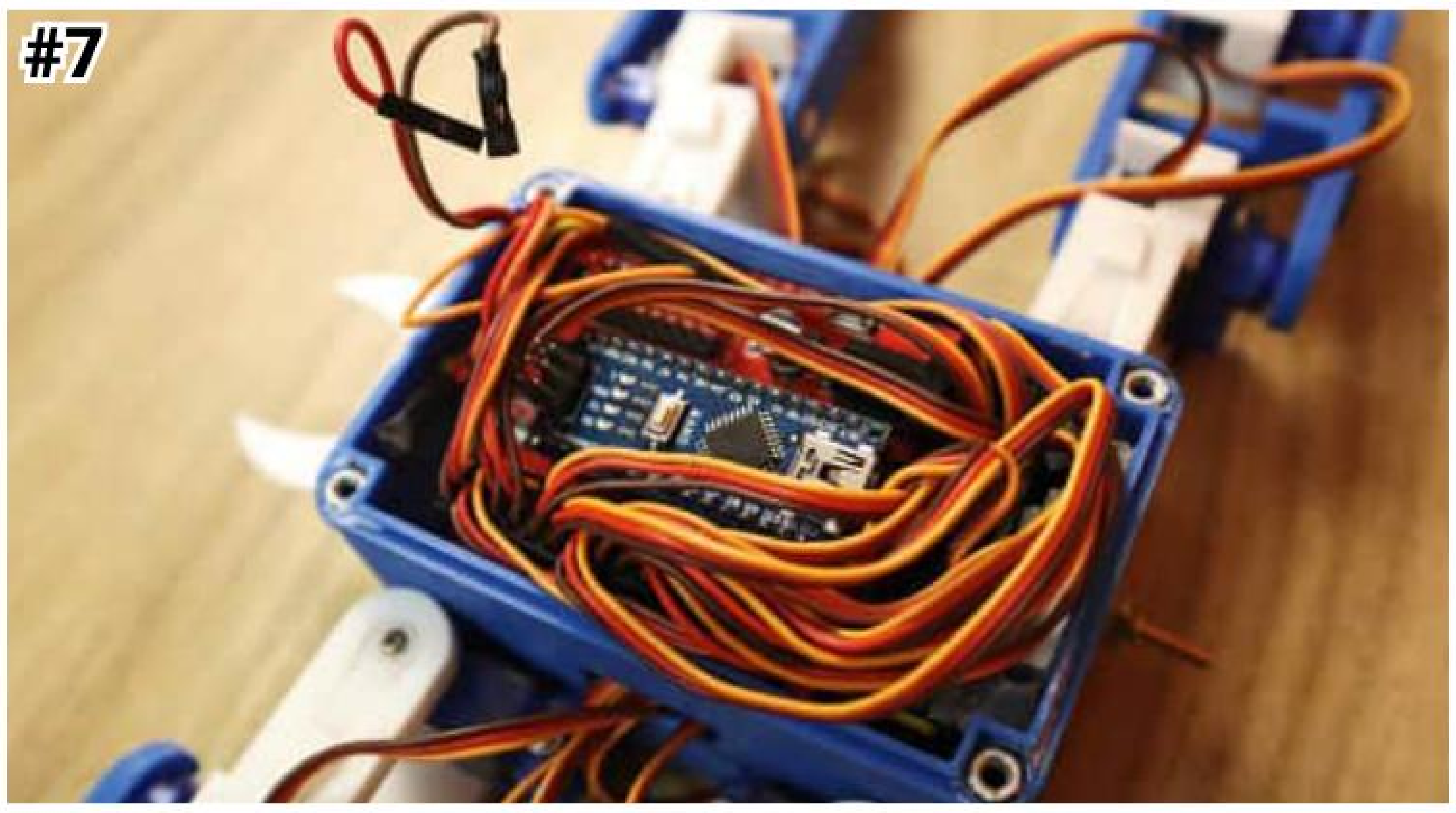


Fig.2: match these servo numbers up with the connections shown in Fig.1.



To start the web control interface, open a console inside the SPY-DER GitHub repository root folder and enter the following commands:

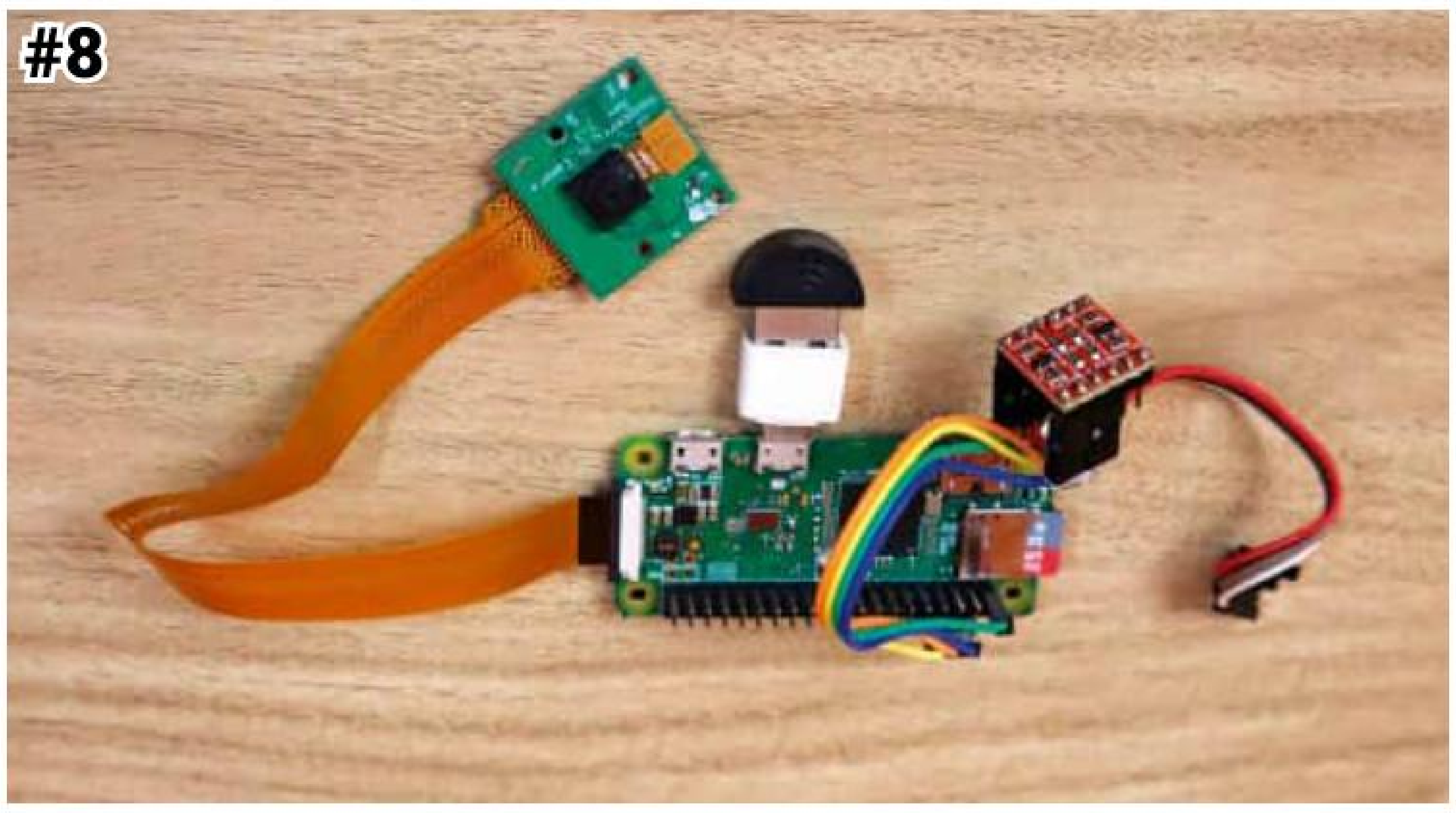
```
cd web_control
python3 web_control.py
```

After running these commands, you can access the web control interface from any browser using the URL **http://<raspberry_pi_ip_address>:5010** (insert the current IP address of your Raspberry Pi) – see Screen 2. From here, the robot can be controlled using all those buttons. You can modify the control interface by changing the code in the **web_control** folder.

Step 13 – Speech control

Go into the **picovoice** folder to run the speech control system. There are three files there you will need. The first one is the main code file named **picovoice_demo_mic.py**. Modify this code according to your speech-to-text model training.

The next file needed is the porcupine keyword file. This is the keyword that you will use to call the robot. There are many pre-trained files available in the Picovoice repository.



You can choose any of the keywords to use as your robot's wake word.

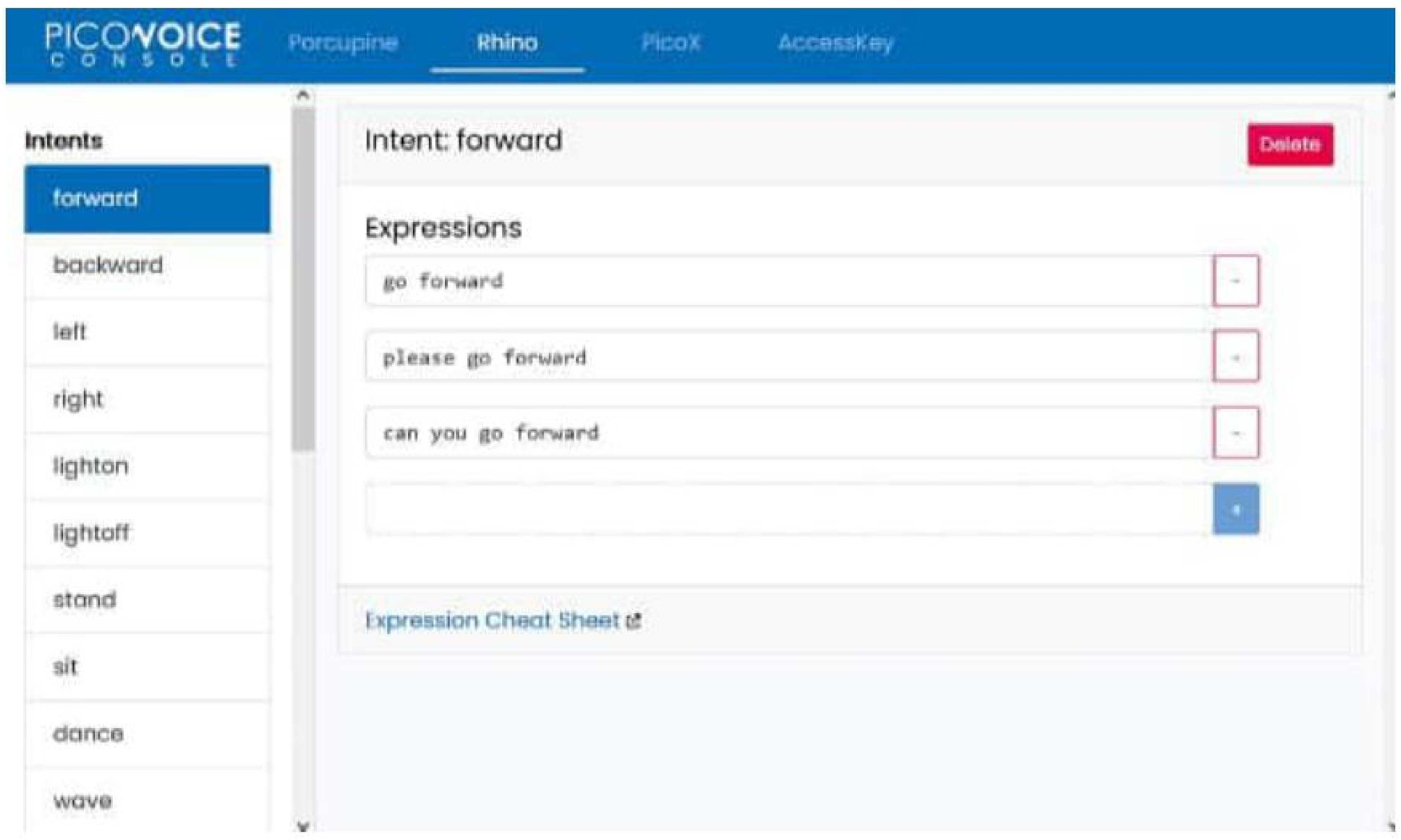
Finally, you need the speech-to-text model, which you have already trained and downloaded. Then you can run the code with these two files using the following commands:

```
cd picovoice
python3 demo/python/picovoice_demo_mic.py \
--keyword_path resources/porcupine/resources/
  keyword_files/raspberry-pi/bumblebee_raspberry-
  pi.ppn \
--context_path your_rhino_model
```

In this example, I have used **bumblebee_raspberry-pi.ppn** as the keyword file, so 'bumblebee' is the wake word for my robot.

Step 14 – Video streaming

You can enable live video streaming either using voice commands or the web control interface. After turning on the live video surveillance, to access it, open the URL **http://<raspberry_pi_ip_address>:80** in a web browser.



Intent: forward

Expressions

go forward

please go forward

can you go forward

Screen 1: the Picovoice Rhino ▲ training console. Here you can teach it how you say the different words that you will later use to control the robot. You'll need to sign up for an account on the Picovoice website to allow you to do this.

Conclusion and future improvements

There is plenty of room for modifications to this project. For example, if a local speech recognition system could be designed that would perform well on a Raspberry Pi, that would speed up its response to voice commands and remove the need for an Internet connection.

Snow-boy hot-word detector is an open-source hot-word detector that works pretty well on the Raspberry Pi. It provides several image processing features like object detection – for example, face recognition. It could potentially be added to this project. Maybe I will upgrade it in the future!

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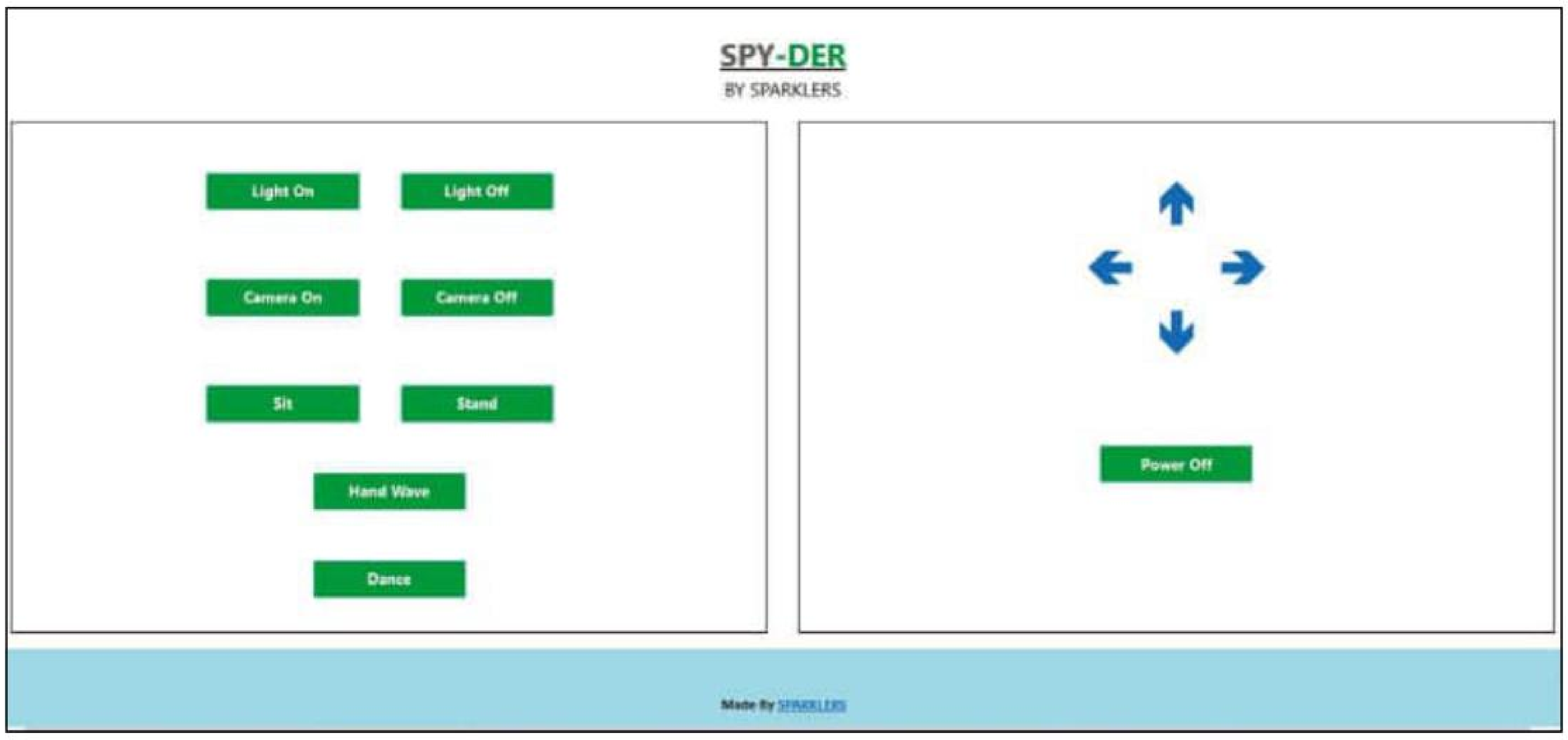
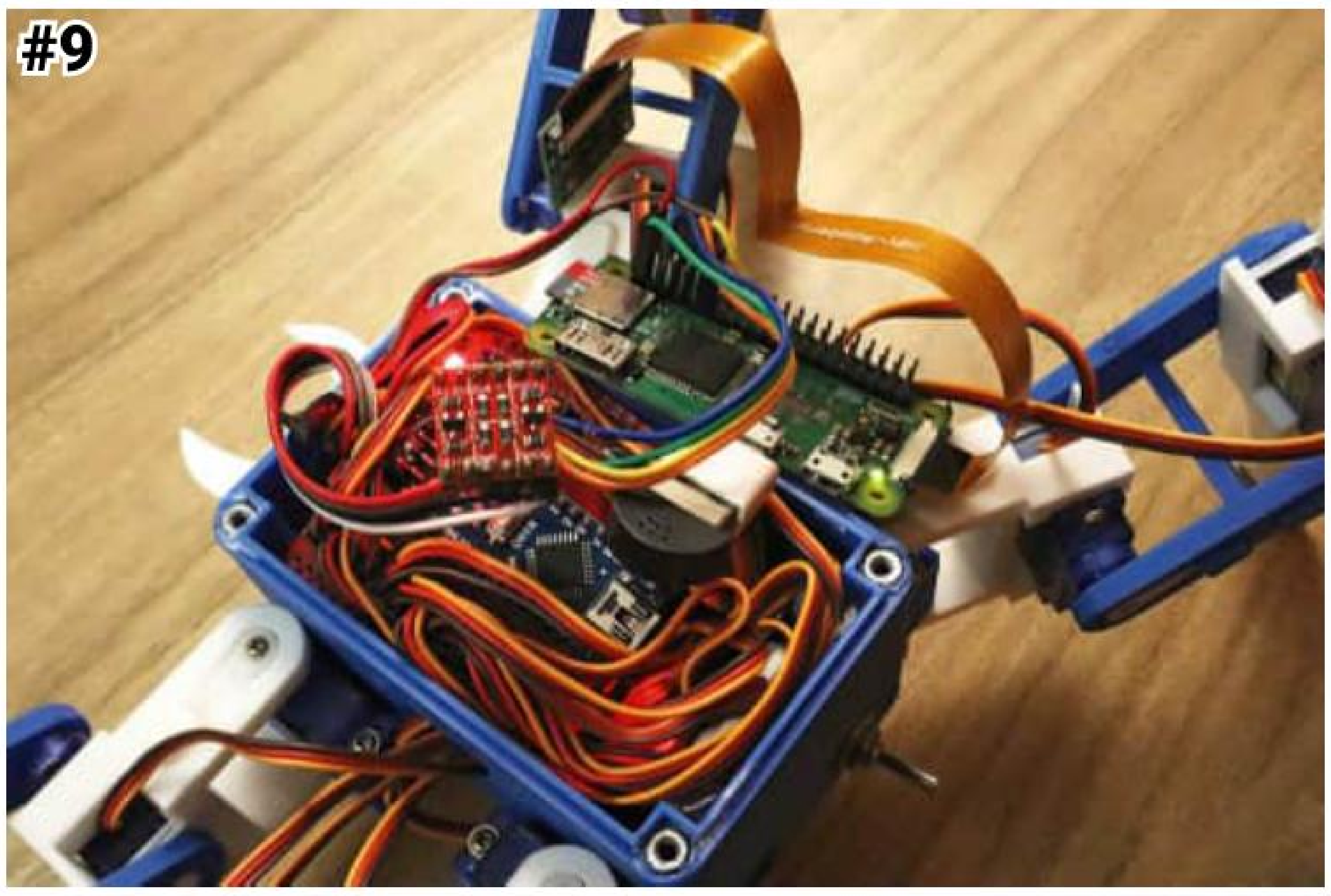
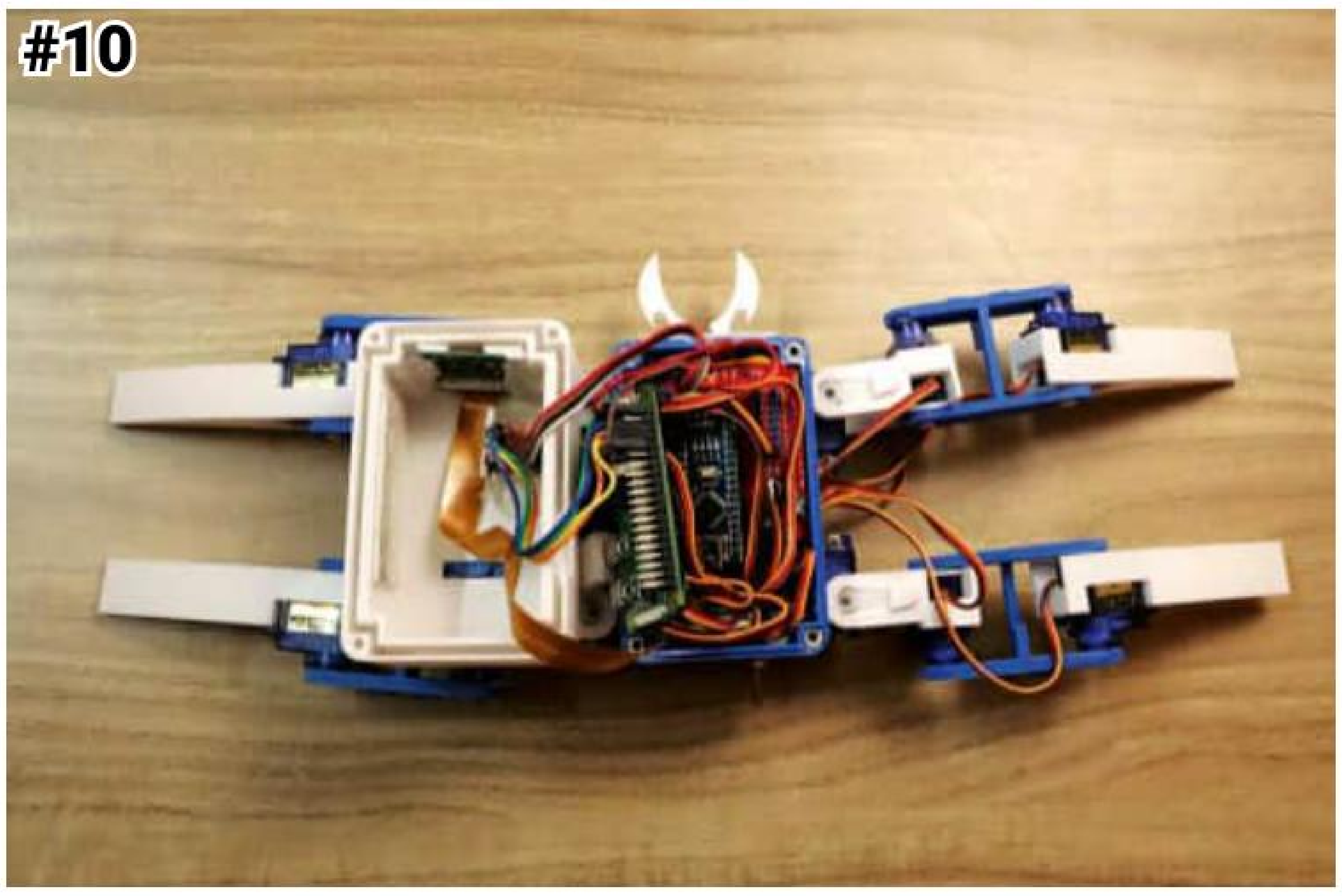


Screen 2: the SPY-DER web ► control interface is quite simple, and all the functions of the buttons are pretty obvious. This works in parallel with voice control, assuming you have voice control up and running.

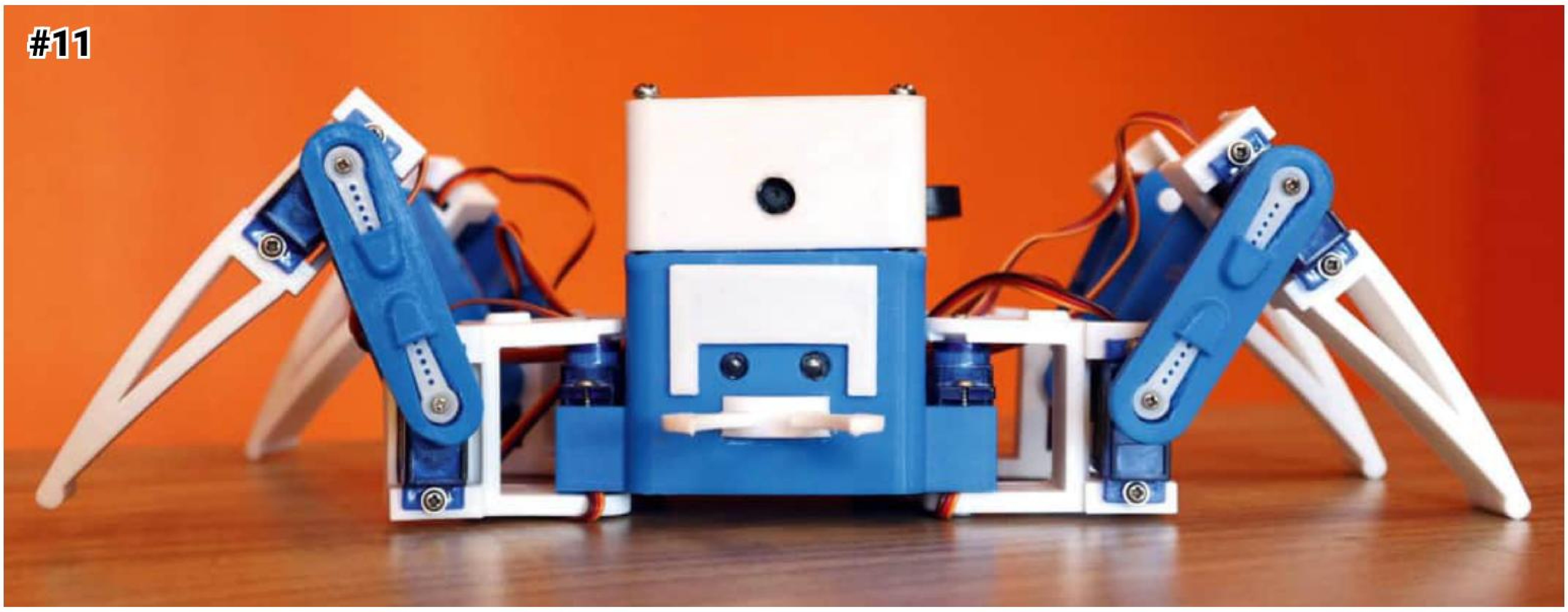
#9



#10



#11



Parts List – SPY-DER Robot

3D printed robot parts – STL 3D printer files available from the August 2023 page of the *PE* website: **https://bit.ly/pe-downloads**
1 Arduino Nano microcontroller module
1 Raspberry Pi Zero W embedded computer
1 Raspberry Pi camera
1 5V to 3.3V logic-level shifter
    [AliExpress https://bit.ly/pe-aug23-spy2]
1 Nano 3.0 Prototype Shield
    [AliExpress item 2044200735]
12 SG90 mini servo motors
    [AliExpress https://bit.ly/pe-aug23-spy3]
1 LM2596-based buck converter module
    [Many on line –eg, eBay item 255123504691]
1 Lithium-ion 2S battery (nominally ~7.4V)
    [eg, from Hobby King or two 18650 Li-ion cells in series]
1 Li-ion 2S battery management system
1-2 bright LEDs (eg, 5mm blue types, for eyes)
1-2 current-limiting resistors for LEDs (eg, 220Ω ¼W)
1 USB microphone
1 USB OTG Micro-B cable or adapter
1 SPST/SPDT switch (eg, toggle or slide) rated 5A DC
4 M2 x 50mm machine screws and nuts
1 pack of DuPont jumper wires (mostly short female-female types)
36 No.2 x 6mm self-tapping screws (may be included with servos)
assorted lengths and colours of medium-duty hookup wire

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Please make sure all components are still available before commencing any project from a back-dated issue.

UNIVERSAL BATTERY CHARGE CONTROLLER

UPDATED

We have made some changes to our Universal Battery Charge Controller published in December 2020 so that it can be built using parts that are actually available. The changes are modest, and the total cost for parts has been reduced.

By John Clarke

Once upon a time, we lived in the land of plenty where electronic components were plentiful and readily available, blissfully unaware of future events that would alter our lives. But all that changed when the COVID-19 pandemic suddenly disrupted many markets and manufacturers.

This affected the production of semiconductor devices and ICs, and dramatically increased the demand for electronics. This has impacted the supply chains for motor vehicles, mobile phones and many white goods such as washing machines and refrigerators, among other items, all of which now depend on semiconductors for their operation.

The resulting lack of semiconductor supply also impacted our readers and us. We regularly heard from readers that a particular part for a project was hard to find and we know how frustrating that can be. Now, more than ever remember to check that all parts are available before spending money on a circuit.

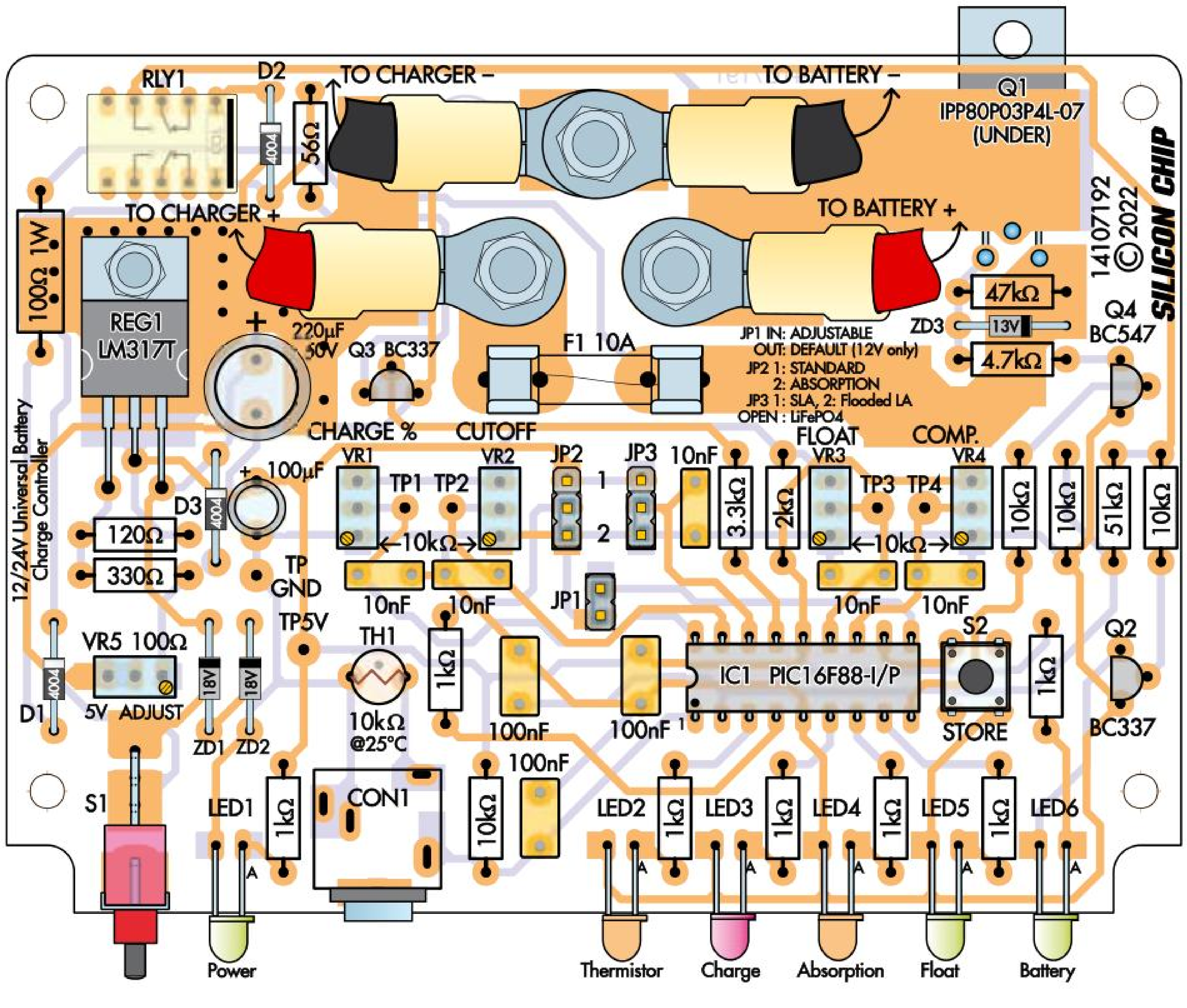

RLY1
D2
TO CHARGER –
TO BATTERY –
Q1
IPP80P03P4L-07
(UNDER)
4004
56Ω
TO CHARGER +
TO BATTERY +
100Ω 1W
REG1
LM317T
220µF
50V
Q3 BC337
F1 10A
47kΩ
ZD3
13V
4.7kΩ
Q4
BC547
14107192
© 2022
SILICON CHIP
JP1 IN: ADJUSTABLE
OUT: DEFAULT (12V only)
JP2 1: STANDARD
2: ABSORPTION
JP3 1: SLA, 2: Flooded LA
OPEN : LiFePO4
12/24V Universal Battery Charge Controller
CHARGE %
CUTOFF
FLOAT
COMP.
VR1
VR2
VR3
VR4
TP1
TP2
TP3
TP4
JP2
JP3
JP1
1
2
10nF
3.3kΩ
2kΩ
10kΩ
51kΩ
100µF
D3
120Ω
330Ω
←10kΩ→
TP GND
TP5V
VR5 100Ω
5V ADJUST
D1
18V
ZD1
ZD2
TH1
10kΩ @25°C
1kΩ
100nF
IC1 PIC16F88-I/P
S2
STORE
Q2
BC337
S1
LED1
LED2
LED3
LED4
LED5
LED6
CON1
A
Power
Thermistor
Charge
Absorption
Float
Battery

Fig.1: construction is much the same as before, except you can skip soldering the SMD IC (IC2) and a few associated capacitors. Instead, install the TO-92 transistor (Q4), two resistors and zener diode ZD3. These components are all in the upper right-hand corner. The rest of the PCB is identical to the original.

Turning to the *Universal Battery Charge Controller*, we used one Si8751 isolated MOSFET driver IC in the circuit, which was unavailable from early 2020 until recently. While back in stock, it is now considerably more expensive than it was when we specified it.

So we have come up with a new circuit that performs the function of the Si8751 in another way. Fortunately, the changes are straightforward. Our discrete MOSFET driver comprises small-signal NPN transistor Q4, a few resistors and zener diode ZD3. The N-channel MOSFET is replaced with a P-channel type.

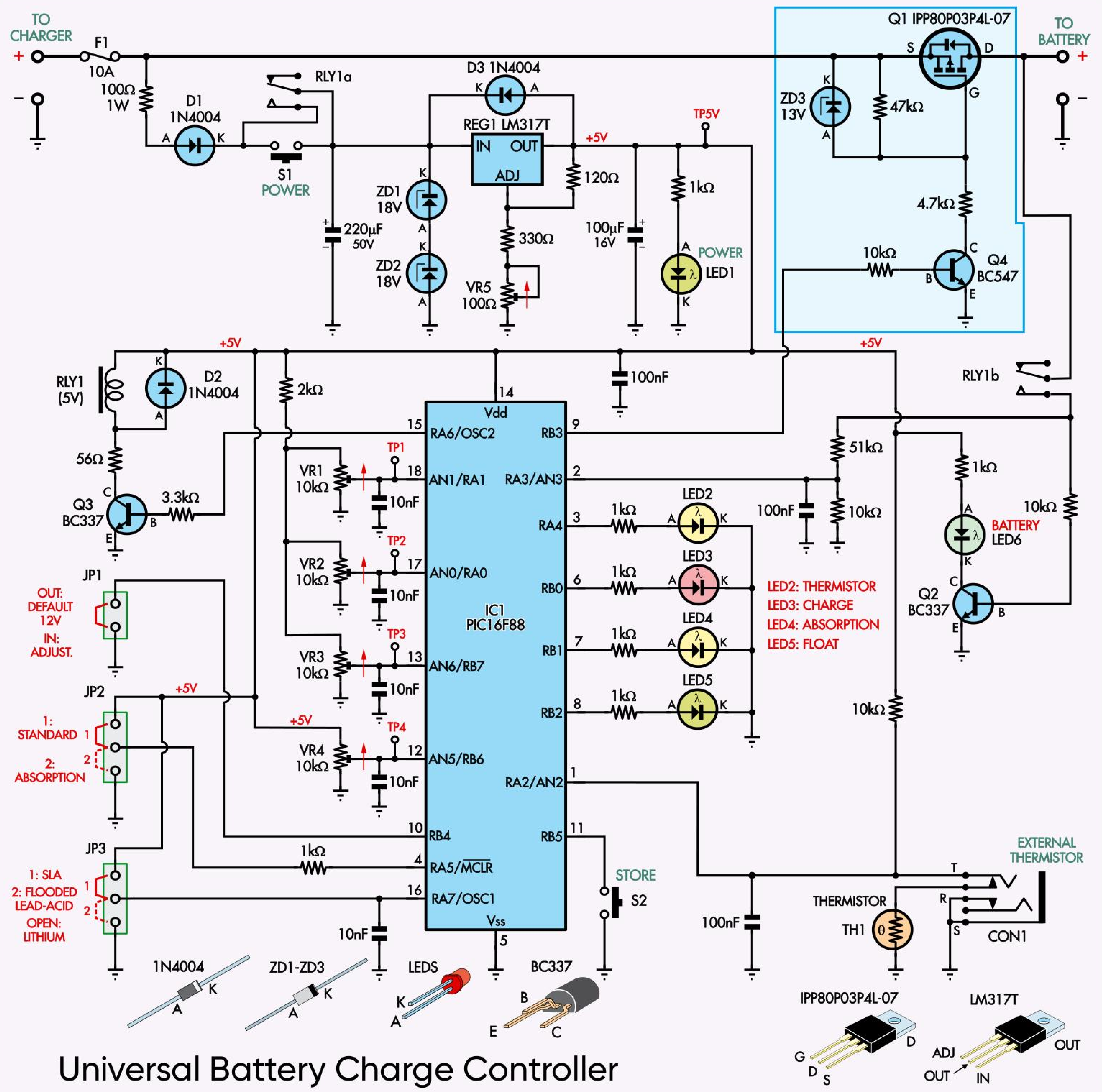
These changes are highlighted in a cyan box in the updated circuit diagram, Fig.2.

The revised version of the PCB, shown in Fig.1, is essentially identical to the original one, except for the MOSFET and gate driver component changes. Also see the Parts List panel below, which outlines the changes in the devices required to build this project.

These changes do not affect the operation of the *Charge Controller* as far as the user is concerned.

Original design

In the original circuit, the Si8751 (IC2) was used to drive the N-channel MOSFET gate (Q1) positive whenever the RB3 output of microcontroller IC1 was high, switching Q1 on. This allowed current to flow from the charger to the battery. When the RB3 output went low, Q1's gate voltage dropped to its source voltage, so the MOSFET was off, and no current flowed to the battery.


TO CHARGER
+
–
F1
10A
100Ω 1W
D1 1N4004
A
K
RLY1a
S1 POWER
220µF 50V
D3 1N4004
REG1 LM317T
IN
OUT
ADJ
ZD1 18V
ZD2 18V
330Ω
VR5 100Ω
120Ω
+5V
TP5V
100µF 16V
1kΩ
POWER LED1
Q1 IPP80P03P4L-07
S
D
G
TO BATTERY
ZD3 13V
47kΩ
4.7kΩ
10kΩ
Q4 BC547
B
C
E
RLY1 (5V)
D2 1N4004
56Ω
Q3 BC337
3.3kΩ
2kΩ
100nF
14
Vdd
15 RA6/OSC2
RB3 9
TP1
VR1 10kΩ
18 AN1/RA1
RA3/AN3 2
10nF
TP2
VR2 10kΩ
17 AN0/RA0
TP3
VR3 10kΩ
13 AN6/RB7
TP4
VR4 10kΩ
12 AN5/RB6
IC1 PIC16F88
RA4 3
RB0 6
RB1 7
RB2 8
RA2/AN2 1
10 RB4
RB5 11
4 RA5/MCLR
16 RA7/OSC1
Vss
5
LED2
LED3
LED4
LED5
LED2: THERMISTOR
LED3: CHARGE
LED4: ABSORPTION
LED5: FLOAT
RLY1b
51kΩ
10kΩ
1kΩ
BATTERY LED6
Q2 BC337
JP1
OUT: DEFAULT 12V
IN: ADJUST.
JP2
1: STANDARD
2: ABSORPTION
JP3
1: SLA
2: FLOODED LEAD-ACID
OPEN: LITHIUM
STORE S2
EXTERNAL THERMISTOR
T
R
S
CON1
THERMISTOR TH1
1N4004
ZD1-ZD3
LEDS
BC337
IPP80P03P4L-07
LM317T
ADJ
OUT
IN

Universal Battery Charge Controller

Fig.2: the only changes in this circuit from the original on page 19 of the December 2020 issue are in the box at upper right. All the components there have been replaced; the N-channel MOSFET is now a P-channel type. This simplifies the driving scheme greatly; it is now an NPN transistor with a few resistors and a zener diode to limit the drive voltage and current to safe levels.

The MOSFET switch on-time with this arrangement was 5ms and the switch-off time was typically 15μs. Fast switching was not required in this application, as we're only switching the MOSFET on and off once every two seconds.

The main reason for using the specialised driver (IC2) in the earlier design was that, with Q1 being an N-channel type and its source connected to the battery, it needed a gate voltage of around 20V to switch on. This is not present anywhere in the circuit; it was generated by stacking the isolated power output of IC2 on top of the battery voltage.

Revised MOSFET driver

Moving on to the updated MOSFET driver circuit, the RB3 output signal from IC1 still controls the MOSFET on and off periods. However, the MOSFET is now a P-channel type, so the higher voltage is unnecessary. It is switched on by pulling its gate voltage below the charger output voltage, which connects to its source terminal.

Switching from an N-channel type to a P-channel type means we have to swap the drain (D) and source (S) terminal connections. That is so that the parasitic internal diode is still facing in the right direction to block current flow to the battery when the channel is not conducting.

Now, when the RB3 output is low, transistor Q4 is off and the gate of MOSFET Q1 is held at its source voltage via the 47kΩ resistor. The MOSFET is therefore off. When the RB3 output goes high, transistor Q4 is switched on via base current through the 10kΩ resistor. The transistor conducts, and the gate of Q1 is pulled towards the ground via a 4.7kΩ resistor.

The 47kΩ resistor between the source and gate forms a voltage divider with the 4.7kΩ pull-down resistor, but since its value is

Parts List – Updated Battery Charge Controller

- **1 double-sided PCB, code 14107192, 111 x 81mm**
- 1 diecast aluminium box, 119 x 94 x 34mm **[Jaycar HB5067]**
- 1 2A DPDT 5V coil telecom relay (RLY1) **[Altronics S4128B]**
- 1 PCB-mount SPDT momentary pubutton switch (S1) **[Jaycar SP0380, Altronics S1498]**
- 1 pushbutton switch cap for S1 **[Jaycar SP0596, Altronics S1482]**
- 1 SPST micro tactile switch with 0.7mm actuator (S2) **[Jaycar SP0600, Altronics S1122]**
- 1 PCB-mount 3.5mm stereo switched socket (CON1) **[Jaycar PS0133, Altronics P0092]**
- 2 PCB-mount M205 fuse clips (F1)
- 1 10A M205 fuse (F1)
- 2 NTC thermistors (10kΩ at 25°C) (TH1 and external thermistor)
- 1 2-way header with 2.54mm spacing (JP1)
- 2 3-way headers with 2.54mm spacing (JP2, JP3)
- 3 jumper plugs/shorting blocks (JP1-JP3)
- 1 18-pin DIL IC socket (for IC1)
- 1 3.5mm stereo jack plug
- 1 TO-220 silicone insulating washer / mounting bush (for Q1)
- 4 6.3mm-long M3 tapped spacers
- 3 M4 x 10mm machine screws
- 3 M4 star washers
- 3 M4 hex nuts
- 2 M3 x 10mm machine screws
- 8 M3 x 5mm machine screws
- 2 M3 hex nuts
- 4 insulated crimp eyelets (wire size 4mm, eyelet for M4 screw)
- 2 cable glands for 4-8mm diameter cable
- 1 2m length of 15A figure-8 automotive cable
- 1 1m length of twin-core shielded cable (for thermistor)
- 1 20mm length of 6mm diameter heatshrink tubing
- 2 large insulated battery terminal alligator clips (red/black)
- 6 PC stakes (optional)
- 4 small adhesive rubber feet

Semiconductors

- 1 PIC16F88-I/P micro programmed with 1410719A.HEX (IC1)
- 1 LM317T 1.5A adjustable positive regulator (REG1)
- **1 IPP80P03P4L-07 P-channel MOSFET (Q1) [Farnell, 2443406]**
- 2 BC337 NPN transistors (Q2, Q3)
- **1 BC547 or BC337 NPN transistor (Q4)**
- 3 green 3mm LEDs (LED1, LED5, LED6)
- 2 orange 3mm LEDs (LED2, LED4)
- 1 red 3mm LED (LED3)
- 2 18V 1W zener diodes (ZD1, ZD2)
- **1 13V 1W zener diode (ZD3)**
- 3 1N4004 1A diodes (D1-D3)

Items in bold have been changed or added

Capacitors

- 1 220µF 50V PC electrolytic
- 1 100µF 16V PC electrolytic
- **3 100nF MKT polyester**
- 5 10nF MKT polyester

Resistors *(all ¼W, 1% metal film unless otherwise stated)*

1 51kΩ	**1 47kΩ**	**4 10kΩ**	**1 4.7kΩ**
1 3.3kΩ	1 2kΩ	7 1kΩ	1 330Ω
1 120Ω	1 100Ω 1W, 5%	1 56Ω	

- 4 10kΩ multi-turn top adjust trimpots, 3296W style (VR1-VR4) (code 103)
- 1 100Ω multi-turn top adjust trimpot, 3296W style (VR5) (code 101)

ten-times higher than the 4.7kΩ resistor, the gate is pulled near to ground. Zener diode ZD3 is included to limit the gate-to-source voltage to 13V to prevent damage to the MOSFET, as it has a gate-source voltage limit of –16V.

The switch-on time for the MOSFET is much faster than before, less than 27µs, and the switch-off time is under 270µs (it's higher because the pull-up resistor value is ten times higher than the pull-down resistor).

So the switch-on is much faster than with the Si8751, but the switch-off period is a bit longer. Still, as mentioned earlier, the switching time does not need to be particularly fast for our circuit.

Part of the reason we have been able to simplify the driving arrangement is that we can now supply high-current P-channel MOSFETs at a reasonable price (see the revised parts list). Traditionally, they have been harder to get and more expensive than equivalent N-channel types.

Construction

There is very little difference in construction between the original and revised PCBs. Refer to Fig.1 and simply fit the new components in the upper right-hand corner as shown. The MOSFET mounting is identical. As a bonus, this change eliminates the only SMD component in the design, the Si8751 (IC2).

Testing, setting up and using the charger are identical to the original and are described in the original *Practical Electronics* article from December 2020.

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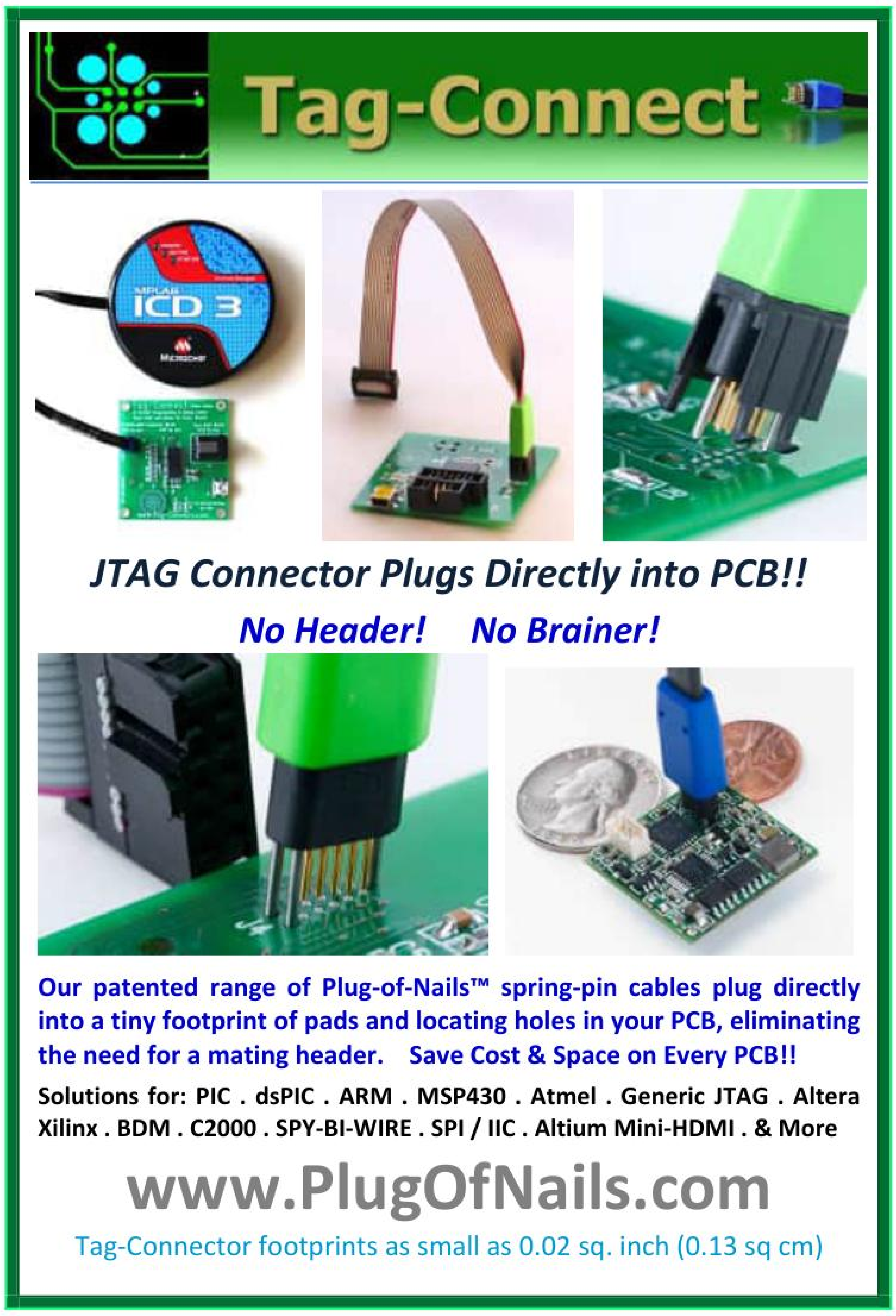

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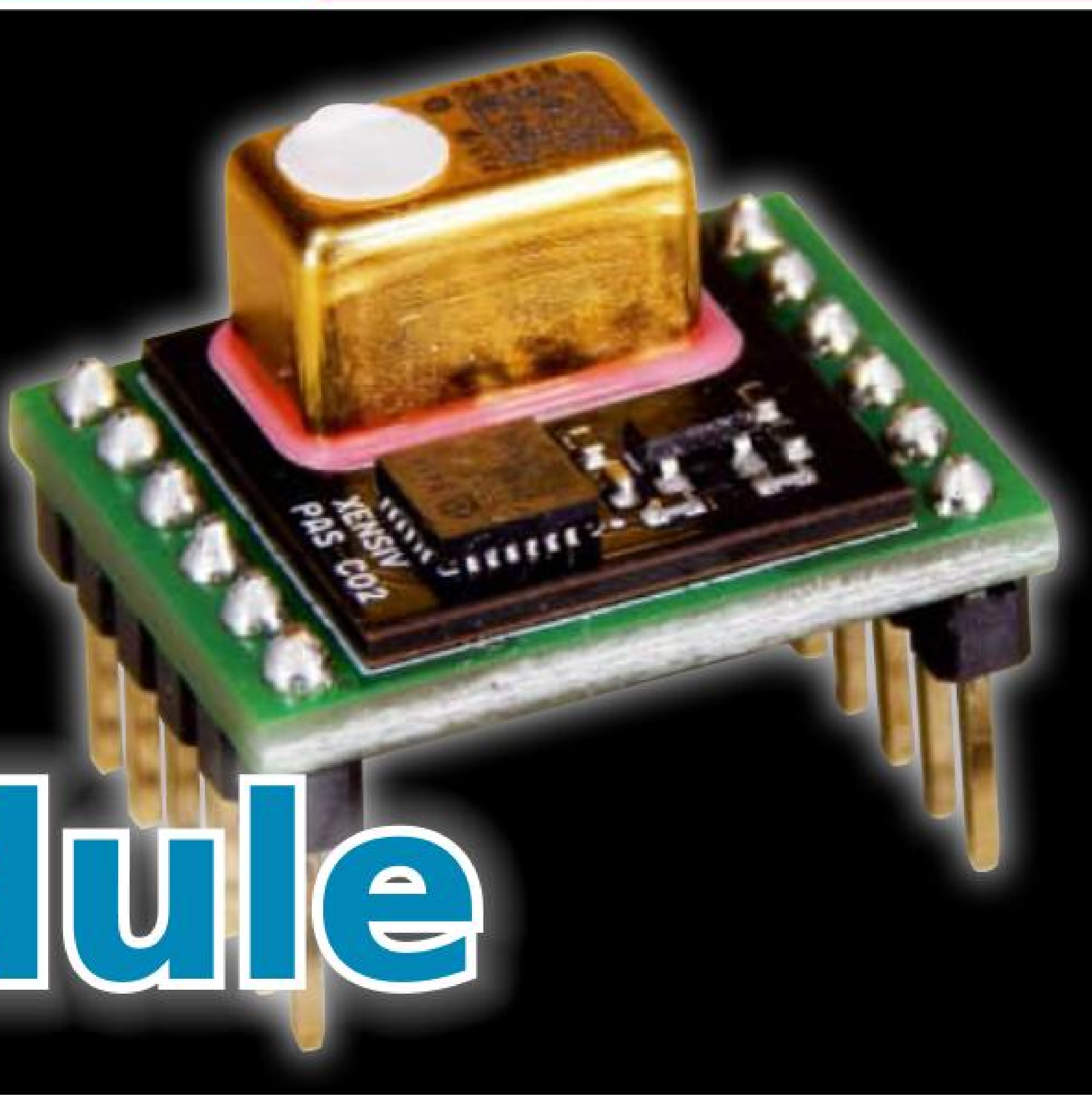
By Jim Rowe

PAS CO_2 Air Quality Sensor Module



Continuing our series of articles describing low-cost air quality sensors (LCAQS), this month, we take a close look at a sensor module based on photo-acoustic spectroscopy, or PAS for short. This time it's the Infineon XENSIV PAS CO_2 mini-board.

Sensors that make use of PAS (photo-acoustic spectroscopy) take advantage of the way molecules of a particular gas absorb specific IR wavelengths according to the Beer-Lambert law.

In PAS sensors, the degree of absorption is measured using a phenomenon Alexander Graham Bell discovered in 1880. When a thin metal disc is exposed to pulses of sunlight (Bell used a rotating slotted wheel), it emits sound. Later, Bell showed that materials exposed to the non-visible wavelengths in sunlight (like infra-red/IR and ultraviolet/UV) also emit sound.

The basic structure of a PAS sensor is shown in Fig.1. On the left is the pulsed IR light source (generally, an array of LEDs), with an optical filter passing only the wavelengths absorbed by the gas to be detected – in this example, 4.2µm for the detection of CO_2.

At the far end of the chamber, there is a MEMS microphone optimised to detect low audio frequencies. When the detected sound level is amplified, it can be converted into a figure corresponding to the amount of CO_2 present in the cell. The whole sensor is enclosed in an acoustic insulation layer, to reduce the influence of external sound.

LCAQS sensors using the PAS principle have only appeared in the last couple of years because their development has depended on MEMS technology. The only one currently available seems to be the XENSIV PAS CO_2 sensor from Infineon Technologies (an offshoot of Siemens in Munich, Germany).

This comes on a very compact module measuring only 14 x 13.8 x 7.5mm, combining the PAS sensor with a dedicated microcontroller unit (MCU) running advanced compensation algorithms and providing a choice of three different data interface ports. It is currently available from suppliers like Farnell/element14 or DigiKey for around £20-£25.

Inside the module

Fig.2 shows a functional block diagram of the XENSIV PAS CO_2 sensor module. At the top is the PAS measurement cell, with its gas inlet pipe on the right, the MEMS IR emitter in the centre and the MEMS LF microphone on the left.

In the lower part of the diagram are the microcontroller and memory, the light-source driver and the circuit that measures the voltage of the external 12V DC supply that is used to power the IR emitter.

As mentioned above, the PAS CO_2 sensor mini-board provides a choice of three different data interfaces for communicating with an external MCU: I^2C, asynchronous serial (UART) and PWM (pulse-width modulation). The one to be used is chosen by setting the logic level on the PSEL and PWM_DIS control pins.

To use the I^2C interface, the PWM_DIS and PSEL pins must be pulled down to GND. For the UART interface,

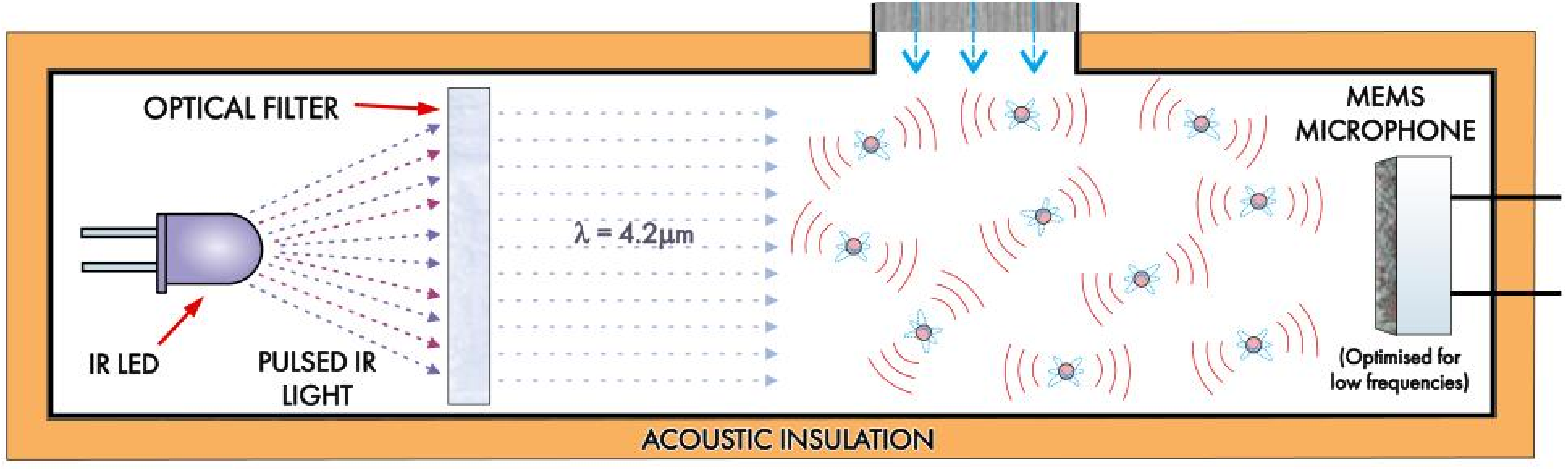
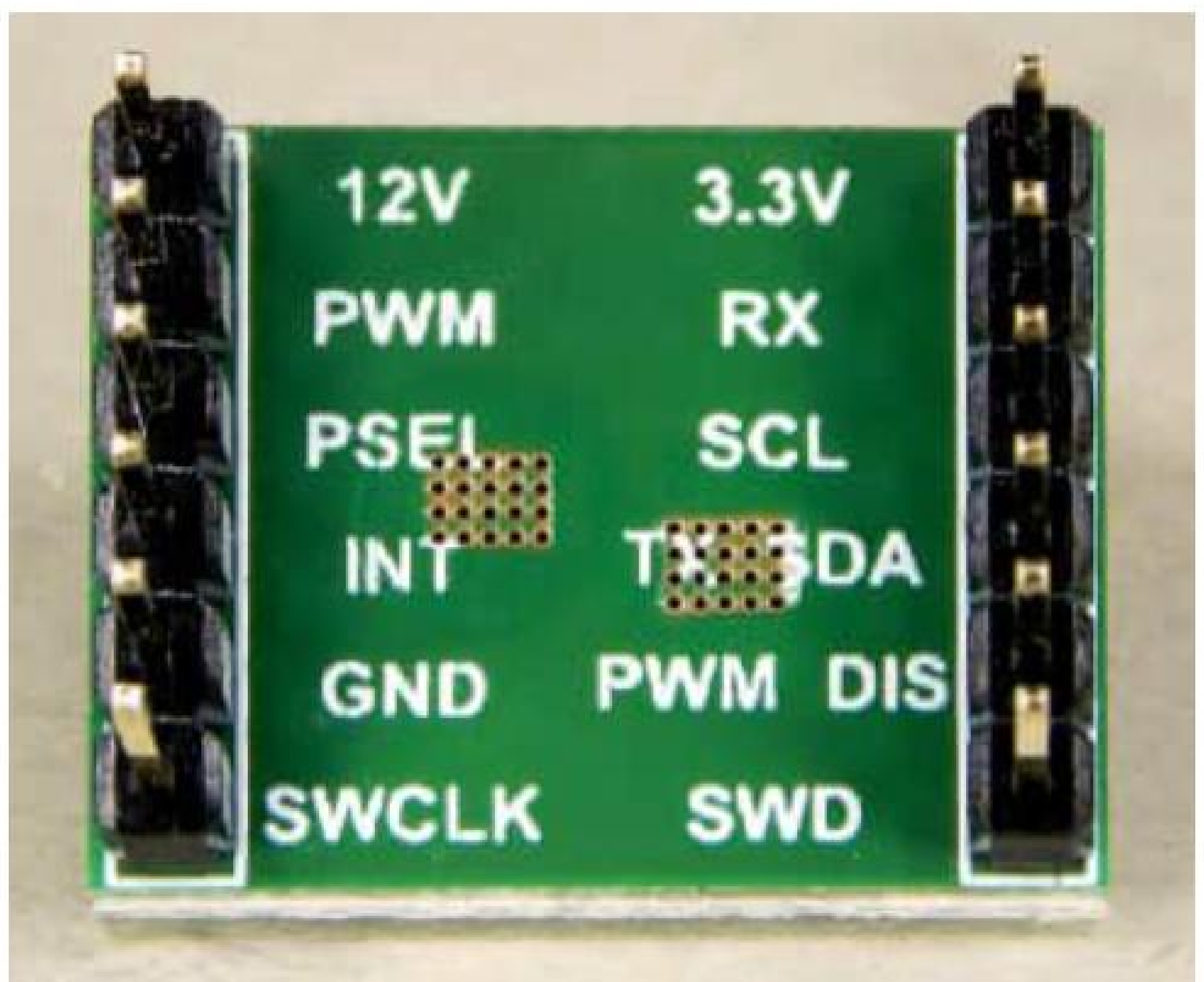


Fig.1: the basic structure of a PAS sensor. A pulsed IR LED emits light through a filter leaving only wavelengths of light that the gas to be detected can absorb. A MEMS microphone then detects low-frequency audio that is emitted by the gas, which can be measured to provide the amount of gas in the cell.



Labels for the pin connections are available on the module underside.

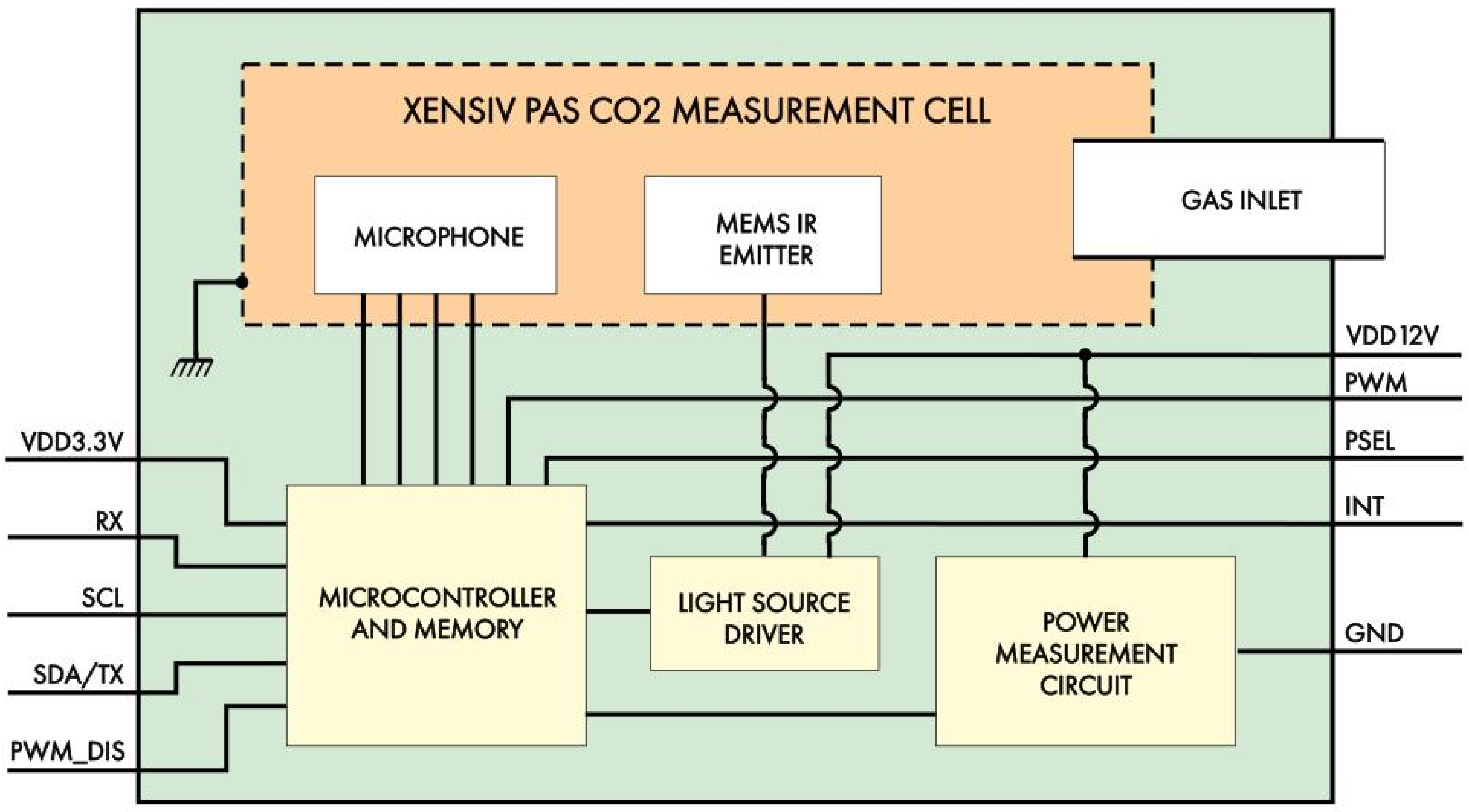

XENSIV PAS CO2 MEASUREMENT CELL
MICROPHONE
MEMS IR EMITTER
GAS INLET
VDD 12V
PWM
PSEL
INT
GND
VDD3.3V
RX
SCL
SDA/TX
PWM_DIS
MICROCONTROLLER AND MEMORY
LIGHT SOURCE DRIVER
POWER MEASUREMENT CIRCUIT

Fig.2: a functional block diagram of the XENSIV PAS sensor module.

PWM_DIS is pulled down while PSEL is pulled up to logic high (3.3V) instead. Finally, if you want to use the PWM interface, the PWM_DIS pin is pulled to logic high (3.3V).

When the I^{2}C interface is selected, the SDA/TX pin is used for the data line and the SCL pin for the clock line. When using this interface, both the SDA/TX and SCL pins need to be fitted with 10kΩ pull-up resistors to the +3.3V supply.

When the UART interface is selected, the SDA/TX line is used as the serial data output and the RX pin for serial data input. But when the PWM interface is selected, the width-modulated pulses emerge from the PWM pin.

The INT pin is an output to allow the internal MCU to indicate when it has finished a measurement. I could not find much information on this item, but I suspect that it is only functional when the UART or PWM interfaces are being used.

The actual pin connections for the PAS CO$_2$ mini-board are shown in Fig.3, which is a simplified top view of the module. There are six pins on each side, but the two lowest pins, labelled SWD and SWCLK, are for testing during manufacture and should not be connected when the module is being used. All of the remaining pins correspond to those shown in Fig.2.

Trying it out

Once I had obtained a sample XENSIV PAS CO$_2$ mini-board module, the challenge was to discover how to connect it to a standard low-cost MCU like an Arduino Uno. Fortunately, I found this information on the Infineon website.

Although Infineon only provides specific information on connecting the module to either a PSoC 6 WiFi-BT Pioneer Kit or an up-market Arduino Due, I was able to glean enough from the latter option to work out how to connect it to an Uno or similar.

This turned out to be relatively straightforward, as you can see from Fig.3, which shows how to connect the module to an Arduino Uno via I^{2}C. The 3.3V logic supply comes from the +3.3V output of the Uno, while the SCL and TX/SDA pins connect to the Uno's SCL and SDA pins and a pair of 10kΩ pull-up resistors. The PWM_DIS and PSEL pins are tied to ground for I^{2}C mode, as mentioned earlier.

Since the module also needs a 12V DC supply to provide power for the IR LED, this can come from a separate plugpack supply. It can be a small supply, since the average current is less than 600µA with brief pulses of around 20mA. Three bypass capacitors on the 12V supply line provide smoothing.

Of course, we need a software library to send commands to and receive data from the sensor, plus a sketch to use the library.

After a bit of searching on the Arduino website in the 'reference/en/libraries' section and then in the list of 900-odd contributed libraries for communicating with sensors, I found one called 'PAS CO2 Arduino Library v1.0.3'.

When I clicked on that one, it took me to **github.com**, where I discovered that the library was provided by and maintained by Infineon! So it was obviously the right one to download.

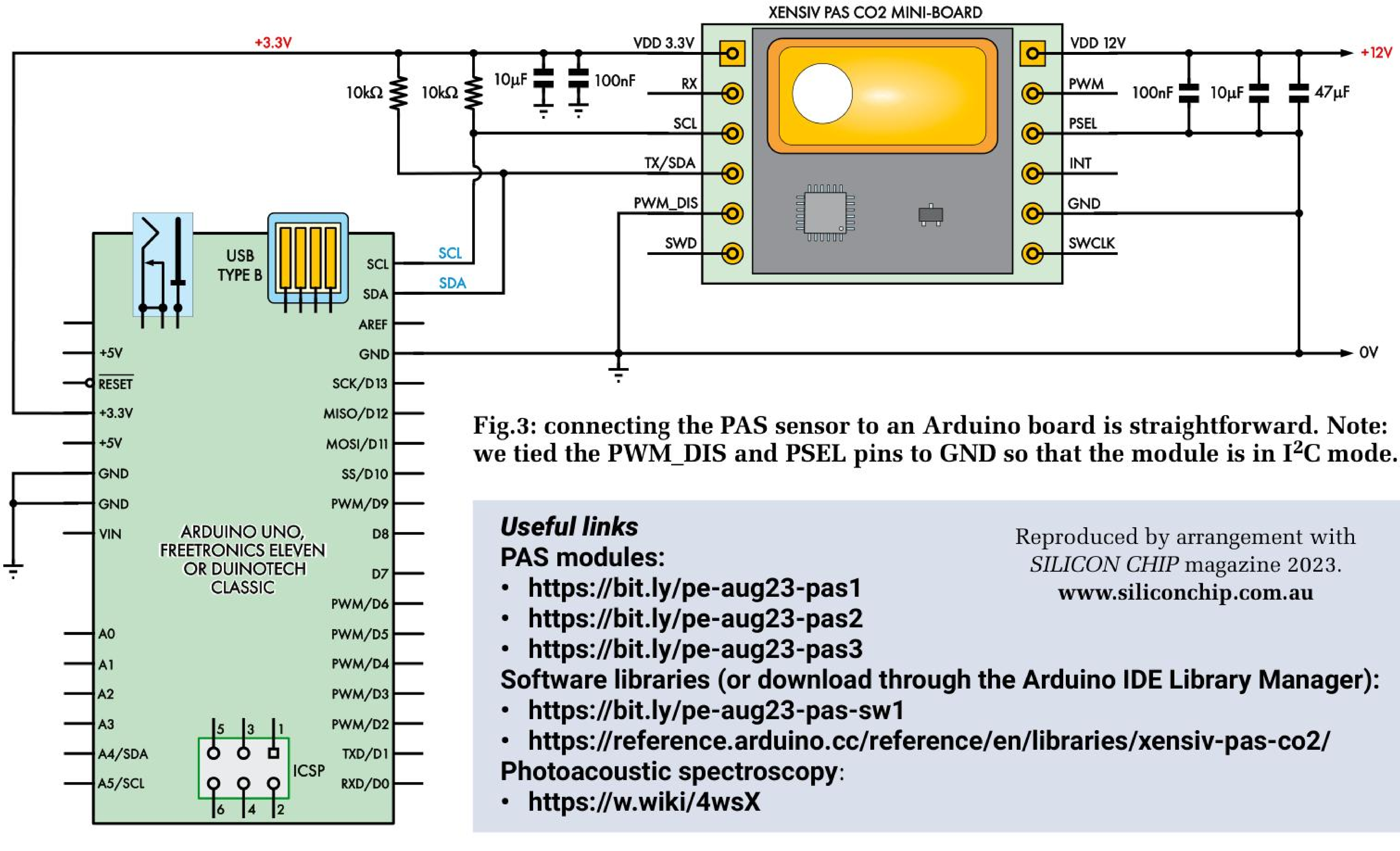

XENSIV PAS CO2 MINI-BOARD
+3.3V
VDD 3.3V
RX
SCL
TX/SDA
PWM_DIS
SWD
VDD 12V
PWM
PSEL
INT
GND
SWCLK
+12V
0V
10kΩ
10kΩ
10µF
100nF
100nF
10µF
47µF
SCL
SDA
USB TYPE B
AREF
GND
SCK/D13
MISO/D12
MOSI/D11
SS/D10
PWM/D9
D8
D7
PWM/D6
PWM/D5
PWM/D4
PWM/D3
PWM/D2
TXD/D1
RXD/D0
+5V
RESET
+3.3V
+5V
GND
GND
VIN
A0
A1
A2
A3
A4/SDA
A5/SCL
ICSP
ARDUINO UNO, FREETRONICS ELEVEN OR DUINOTECH CLASSIC

Fig.3: connecting the PAS sensor to an Arduino board is straightforward. Note: we tied the PWM_DIS and PSEL pins to GND so that the module is in I^{2}C mode.

Useful links

PAS modules:
- **https://bit.ly/pe-aug23-pas1**
- **https://bit.ly/pe-aug23-pas2**
- **https://bit.ly/pe-aug23-pas3**

Software libraries (or download through the Arduino IDE Library Manager):
- **https://bit.ly/pe-aug23-pas-sw1**
- **https://reference.arduino.cc/reference/en/libraries/xensiv-pas-co2/**

Photoacoustic spectroscopy:
- **https://w.wiki/4wsX**

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I downloaded the library zip file and added it to my Arduino IDE's list of installed libraries. I then discovered that it came with 12 example sketches – four of which are for using the module's PWM interface mode, while the other eight are for the serial interface modes (ie, I^2C or UART). The latter had the following titles:

- serial-alarm
- serial-api-test
- serial-calibrate
- serial-device-id
- serial-diagnosis
- serial-oneshot
- serial-periodic
- serial-reset

Fig.4: sample output

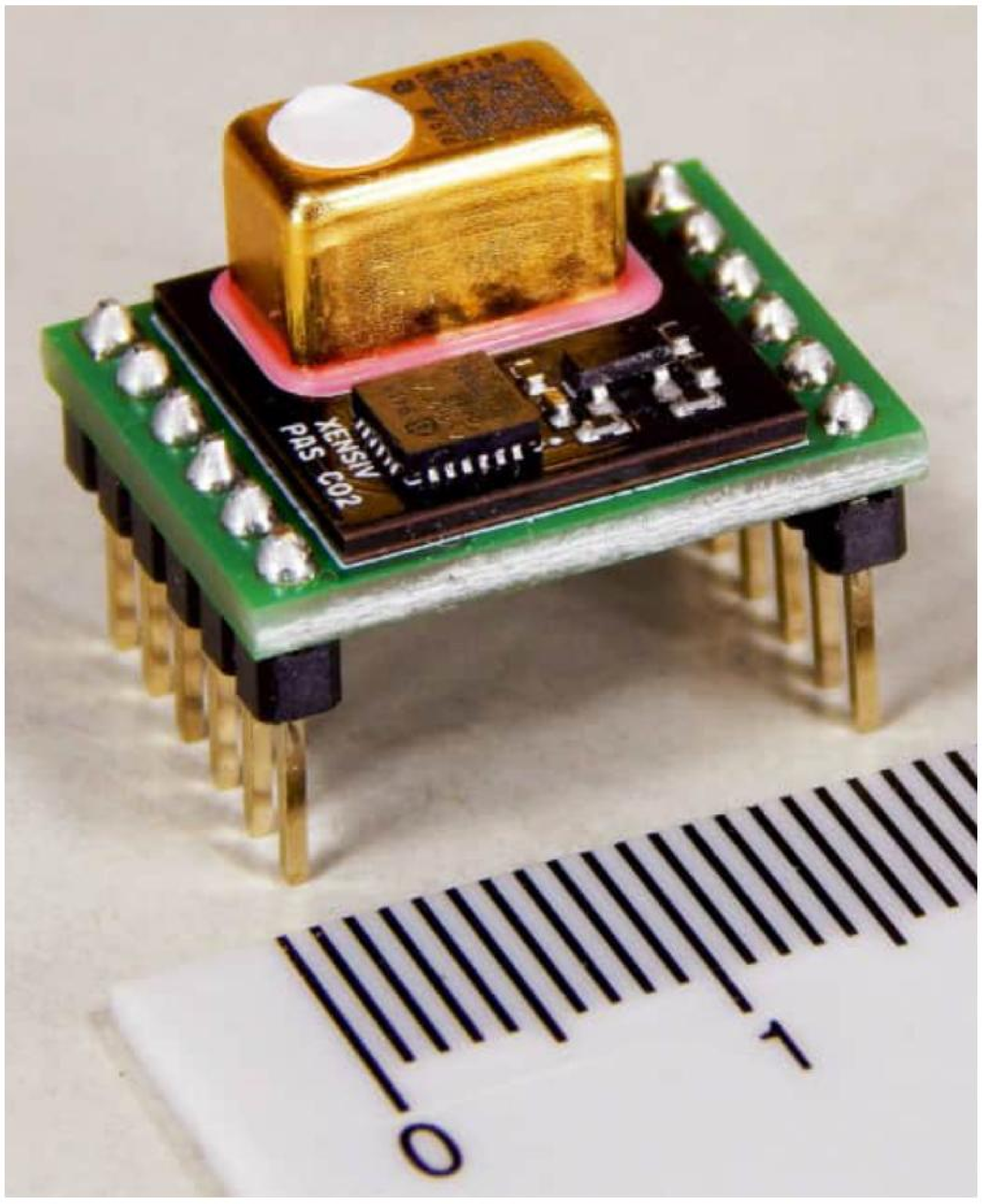
```
15:37:04.303 -> pas co2 serial intialized
15:37:09.505 -> co2 ppm value : 633
15:37:14.520 -> co2 ppm value : 623
15:37:19.487 -> co2 ppm value : 621
15:37:24.502 -> co2 ppm value : 611
15:37:29.516 -> co2 ppm value : 609
15:37:34.483 -> co2 ppm value : 610
15:37:39.498 -> co2 ppm value : 649
15:37:44.466 -> co2 ppm value : 1018
15:37:49.480 -> co2 ppm value : 1255
15:37:54.448 -> co2 ppm value : 1254
15:37:59.462 -> co2 ppm value : 1256
15:38:04.477 -> co2 ppm value : 1317
15:38:09.444 -> co2 ppm value : 1409
15:38:14.459 -> co2 ppm value : 1418
15:38:19.426 -> co2 ppm value : 1405
15:38:24.441 -> co2 ppm value : 1392
```

I decided to try **serial-oneshot.ino**, and when I loaded it, compiled it and then uploaded it to the Arduino and opened virtual serial port COM3, it all sprang into life.

Fig.4 shows the output in the Arduino IDE Serial Monitor following the startup of the serial-oneshot sketch. The first line indicates that the PAS CO_2 and its I^2C serial port have been initialised, while the following lines show the measured CO_2 levels in ppm (parts per million). These measurements are about five seconds apart, as you can see from the timestamps.

The other thing to note from Fig.4 is that the initial seven readings are all between 610ppm and 649ppm, whereas the eighth reading suddenly jumps up to 1018ppm and then following readings move up to 1418ppm before starting to fall again.

At about 15:37:40, I exhaled towards the PAS CO_2 sensor. So it was responding to the sudden increase in CO_2 level, as it's supposed to.



The PAS sensor measures 14 x 13.8mm, making it tiny in comparison to the enlarged photo shown here.

Encouraged by this initial success, I then tried loading, uploading and running the **serial-calibrate.ino** example sketch. This sketch ran very quickly, simply giving a 'sensor now calibrated' message before ending.

Summary

Despite being very compact, the Infineon XENSIV PAS CO_2 sensor mini-board is a good performer. As it uses a standard I^2C interface, it is compatible with just about any microcontroller, including virtually all Arduinos.

No doubt it would work with a Micromite as long as it was set up to send the correct I^2C commands.

Although it is priced higher than the MOS sensors we've looked at previously, and it needs a 12V supply, it is a good choice if you want a small and accurate CO_2 sensor.

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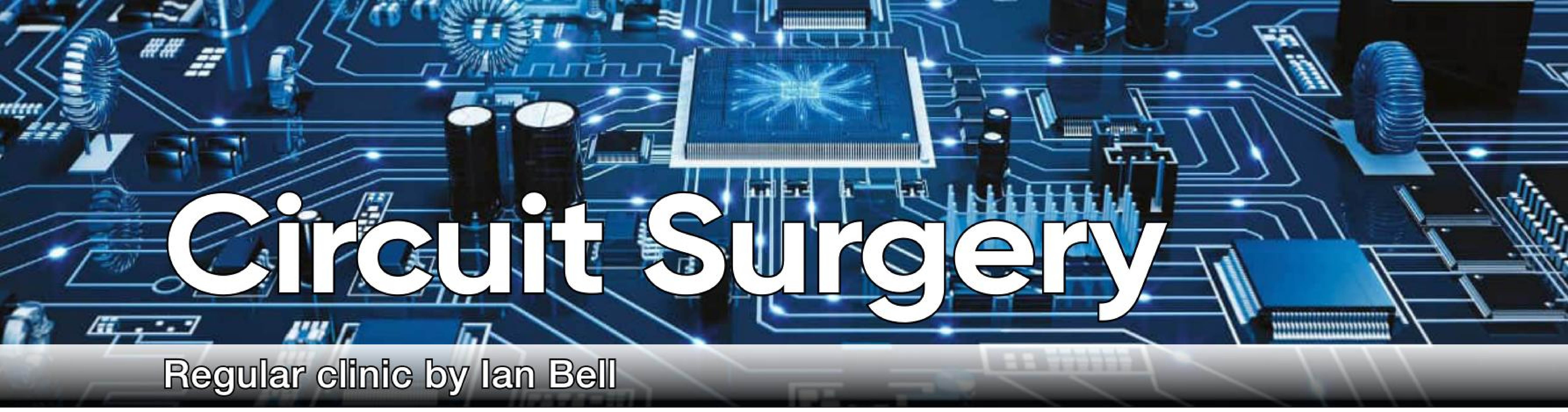


Circuit Surgery

Regular clinic by Ian Bell

Ideal diode integrated circuits

Last month, inspired by a question on EEWeb forum, we looked at diode power circuits and the 'ideal diode' circuits which can be used in place of diodes in these applications. We mainly covered the basic principles. This month, we follow on by exploring in more depth some of the ICs which are used to implement ideal diode power circuits.

Diode power circuits

To recap, the diode power circuits which we were discussing last month are used for reverse-power protection and diode ORing of power supplies – see Fig.1 and Fig.2 respectively. Reverse-power protection uses the fact that diodes can only conduct in one direction to prevent circuits from being damaged by reversal of the supply voltage. This easily occurs due to user installation error in battery-powered systems. Another possible reverse-power scenario is transient reverse voltage due to inductive load switching on the same supply (a common problem in automotive electronics).

Diode-OR circuits allow multiple supplies to be connected to the same circuit. If only one supply is connected then its associated diode will conduct, and that circuit will behave in the same way as with a single reverse protection diode. If both supplies are present, with one sufficiently higher than the other, then the higher supply will provide all the power to the load. If both supplies have very similar voltages, then both supplies can deliver power to the load (load sharing).

Conducting diodes have a forward voltage drop (V_F) and diode current (I_F), therefore they dissipate power $V_F I_F$, which can be a problem in terms of both energy loss and heat management. The diode voltage drop can also reduce effective battery life. These problems can be reduced if Schottky diodes are used instead of standard silicon diodes, due to their lower voltage drop at comparable currents, but this does not eliminate the problem.

Ideal diode controllers

As discussed last month, a MOSFET can be used in place of a diode for reverse protection, with the advantage of lower voltage drop and power dissipation. However, MOSFETS may conduct in the reverse direction in certain situations, which can cause significant problems in some applications. Many circuits require reverse-current protection as well as reverse-supply-voltage protection, and we will discuss this in more detail later. The diode-OR circuit can also make use of MOSFETs, but this requires appropriate gate control to switch the individual MOSFETS correctly (or balance operation in load sharing).

With appropriate control, a MOSFET can behave in a manner close to an ideal diode in a reverse-voltage protection or diode ORing circuit. By 'ideal diode' we mean, low voltage-drop and low power dissipation compared with using standard diodes; reverse-current protection; and accurate switching between conducting and non-conducting states. The circuitry providing this functionality is called an 'ideal diode controller' and numerous ICs are available which provide this facility. They vary in their specific target applications, features and capabilities. A generic ideal diode circuit is shown in Fig.3, this is equivalent to the circuit in Fig.1. The diode symbol in Fig.3 represents the body diode of MOSFET M1, not a diode component.

LTC4358 ideal diode

The LTC4358 IC is a '5A Ideal Diode' device developed by Linear Technology (now Analogue Devices). It is called an 'ideal diode' rather than an 'ideal diode controller' because it has an internal MOSFET. The word controller refers to control of an external MOSFET in the terminology of these devices. The LTC4357 is a similar device which uses an external MOSFET and is described as a 'Positive High Voltage Ideal Diode Controller'. Both devices are aimed at diode-OR applications for redundant power supplies and can regulate load sharing. The LTC4358 provides reverse-current protection, but does not provide reverse-voltage input protection. We will look at the LTC4358 in detail and use some simplified simulations to help explain its operation.

A block diagram of the LTC4358 is shown in Fig.4. The In, Out and Gnd pins correspond with the generic ideal diode controller in Fig.3. The Drain pin is connected to the internal MOSFET drain and corresponds with the MOSFET drain in Fig.3. This must be connected to the Out pin. The drain is connected to an exposed pad on the base of the IC package (see Fig.5) and is used to conduct heat to PCB copper, which acts as a heat sink. The Gate pin corresponds with

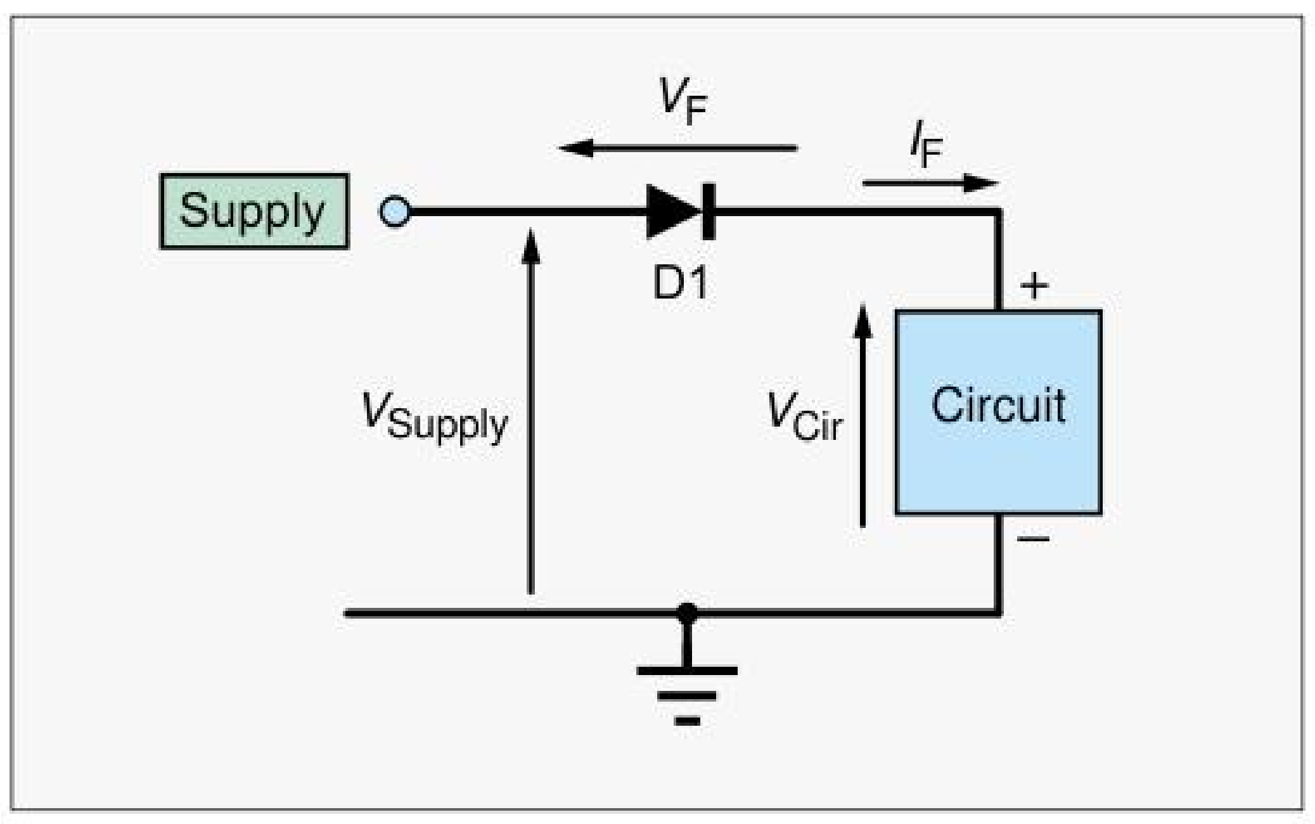


Fig.1. Circuit with reverse-voltage protection diode.

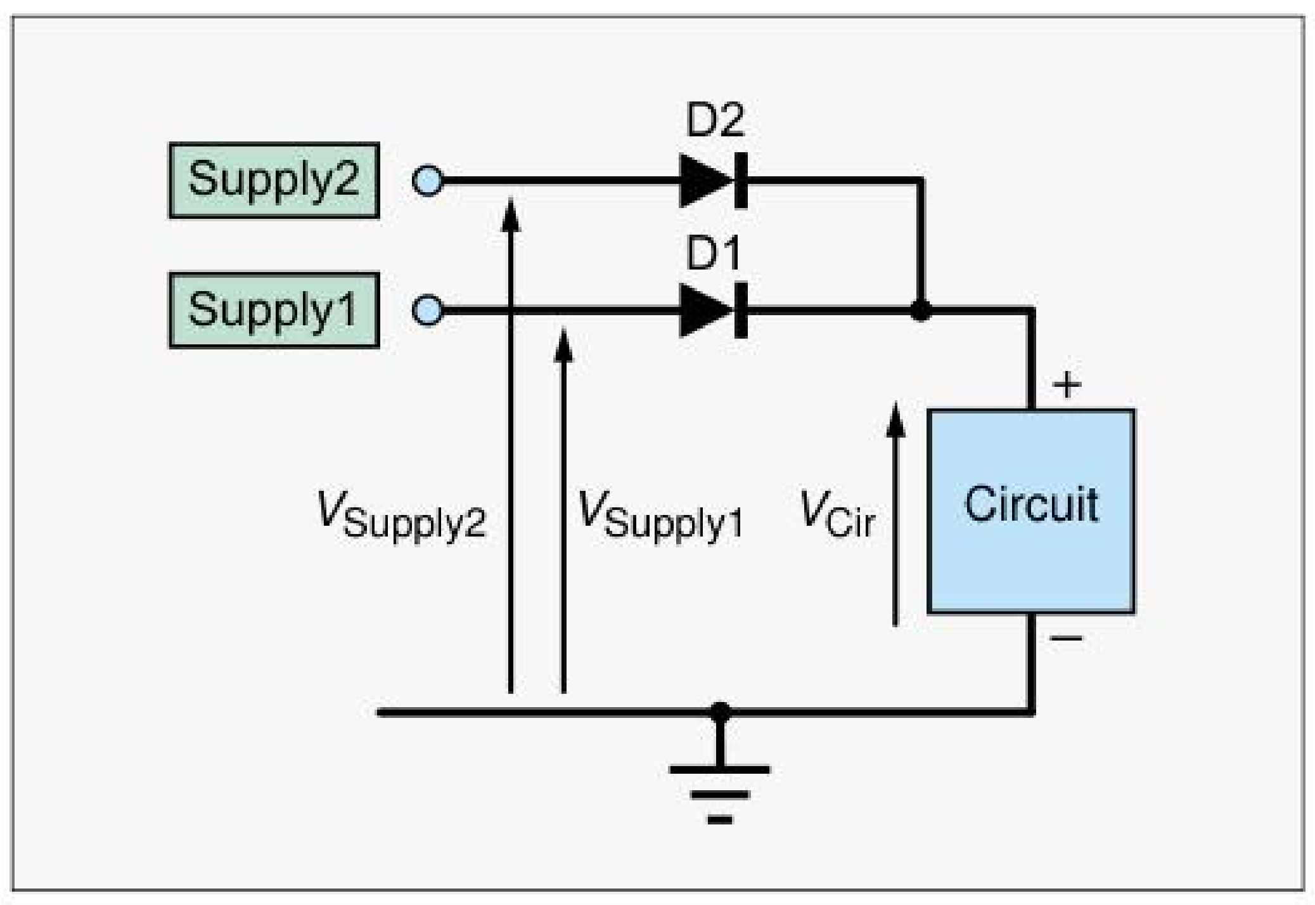


Fig.2. Diode-OR power source circuit.

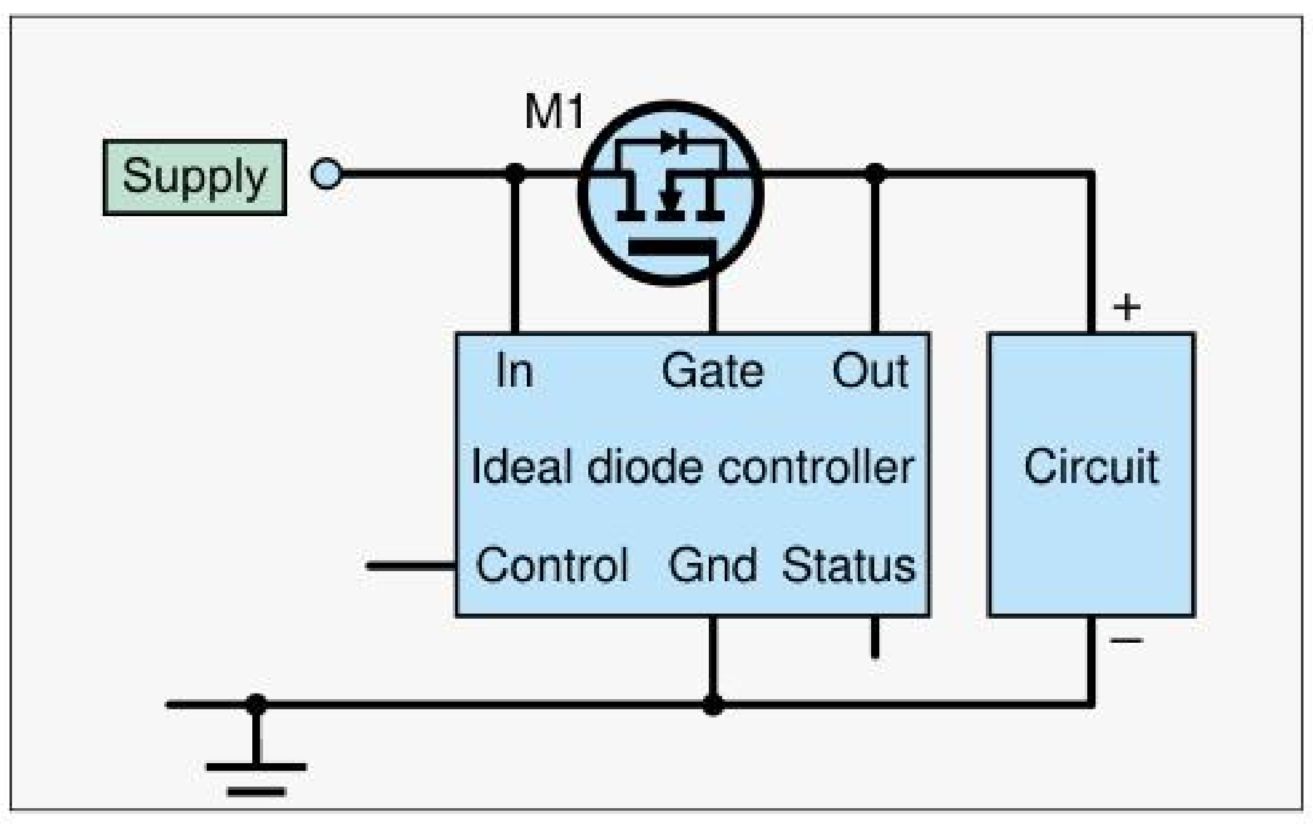


Fig.3. Circuit demonstrating ideal diode controller concept.

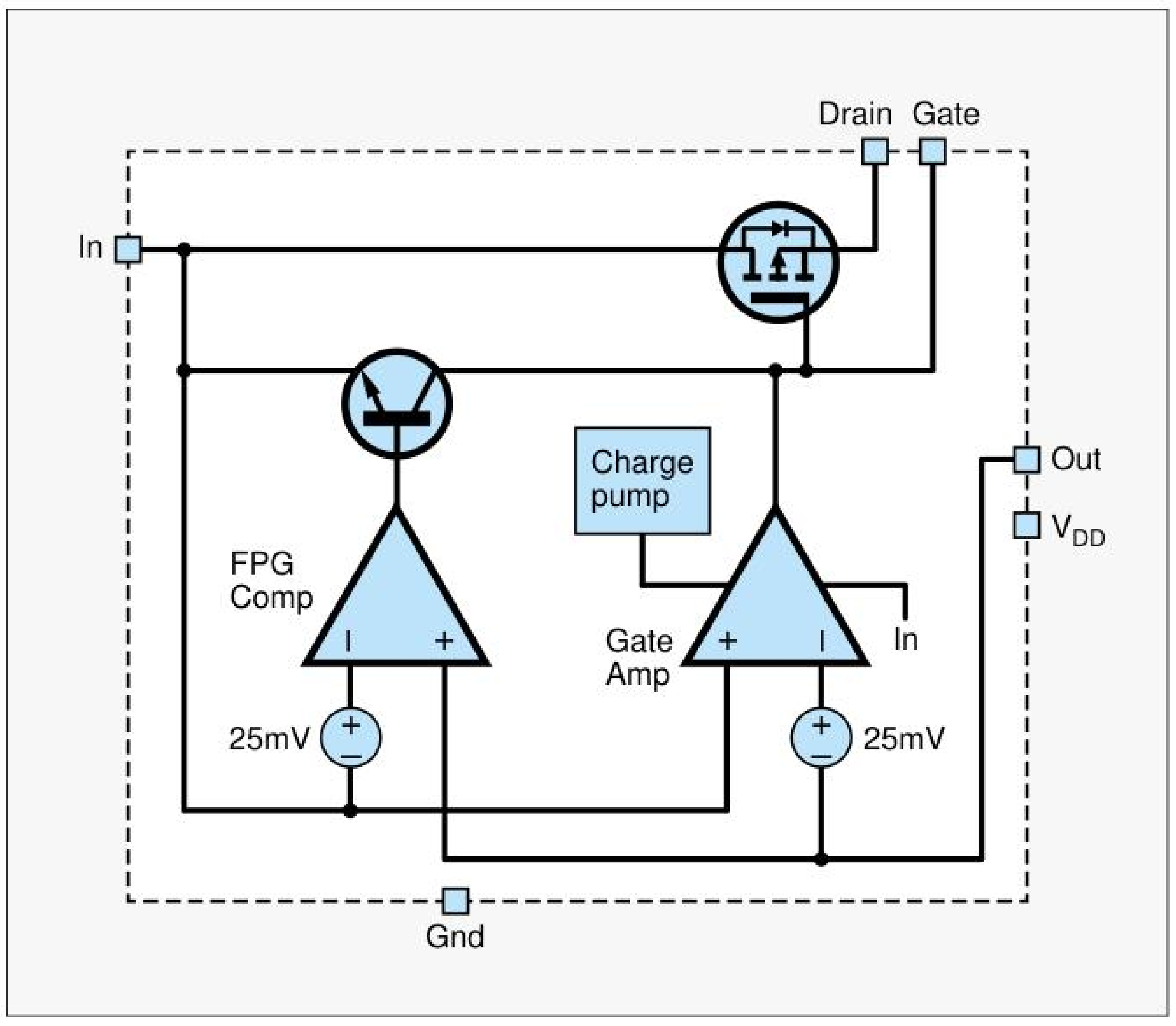


Fig.4. LTC4358 block diagram. (Based on Analog Devices/LT datasheet)

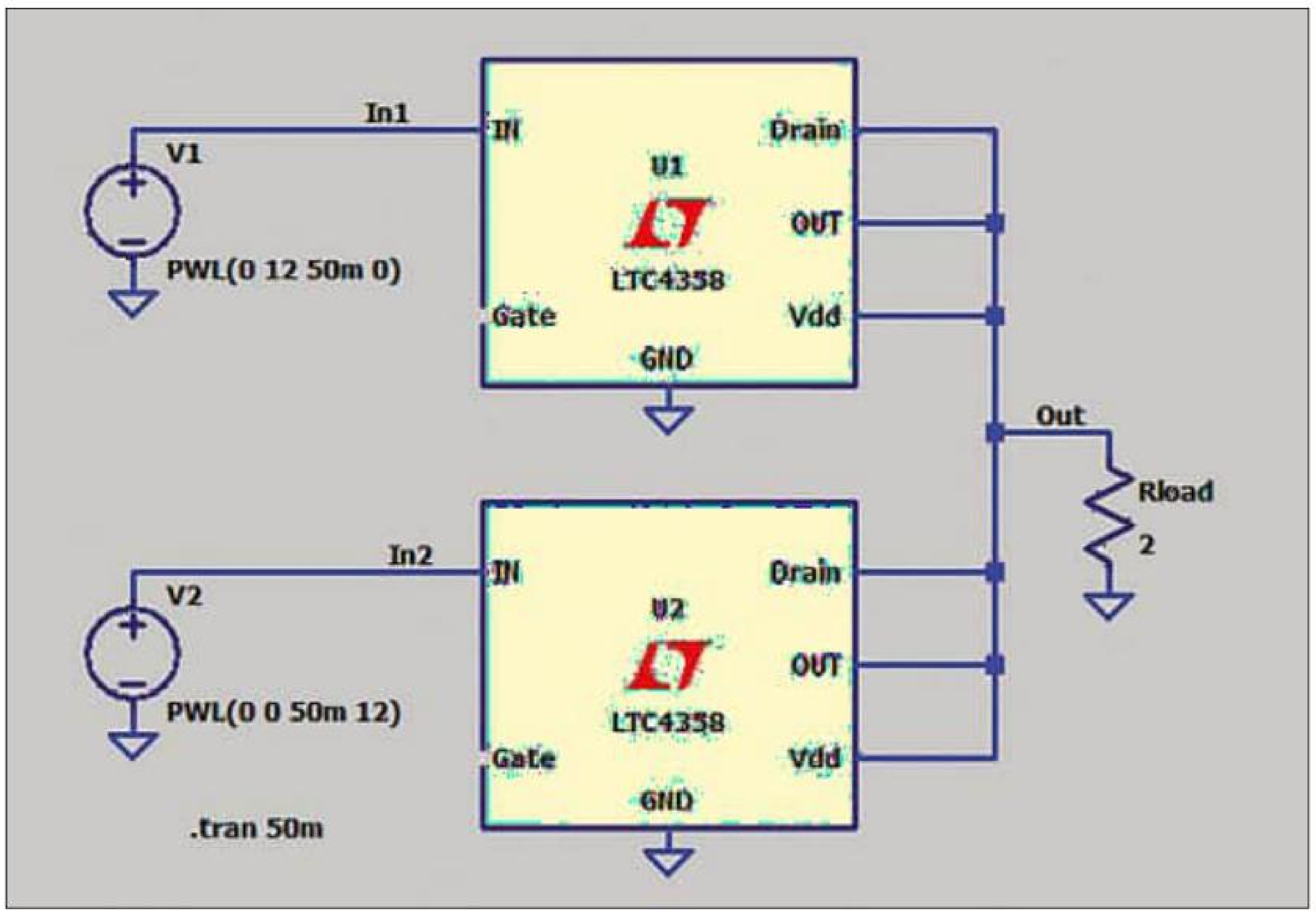


Fig.6. LTspice schematic of Diode-OR circuit using two LTC4358 ideal diode ICs. Based on the example provided with LTspice.

the Gate pin in Fig.4, but as the MOSFET is internal this pin is not normally connected to anything externally. However, it could be used to monitor the gate control. The V_{DD} pin is the device's power supply (which is not shown in Fig.3); it is typically connected directly to the Out pin.

The LTC4358's block diagram in Fig.4 shows two subcircuits involved in the control of the MOSFET via its gate voltage. During normal operation, when the MOSET is conducting, the Gate Amplifier is used to regulate the voltage across the MOSFET to be 25mV where possible. The FPD Comparator (Fast Pull Down Comparator) is used to rapidly switch off the MOSFET in situations where reverse current would otherwise flow through the MOSFET. (This provides the reverse-current protection mentioned above). We will look at simplified simulations of the Gate Amplifier and FPD Comparator subsystems separately to help explain operation of the device.

To switch on the MOSFET, the voltage at its gate must be positive with respect to its source, so, given that its source and drain are at, or close to, the source supply voltage when the MOSFET is conducting, the gate voltage, and hence the output of the Gate Amplifier, must be higher than the supply voltage. This means that the Gate Amplifier requires a higher supply voltage than the source supply. This is achieved in the LTC4358 (and many similar devices) by using a charge pump circuit (as shown on Fig.4).

Charge pumps work by charging and switching capacitors. For example, if a capacitor is charged up to the supply voltage and then switched so that what was the ground end is now connected to the positive supply, then the other side of the capacitor (previously connected to the supply) will be at twice the supply voltage relative to ground. This voltage can be used to charge another capacitor to (towards) twice the supply voltage. By constantly switching between these two arrangements the second capacitor's charge is 'pumped up' to provide (and maintain) twice the supply voltage. As long as any current taken from the second capacitor is small compared to the available average 'pump up' current it can be used as a power supply for parts of the circuit that need it.

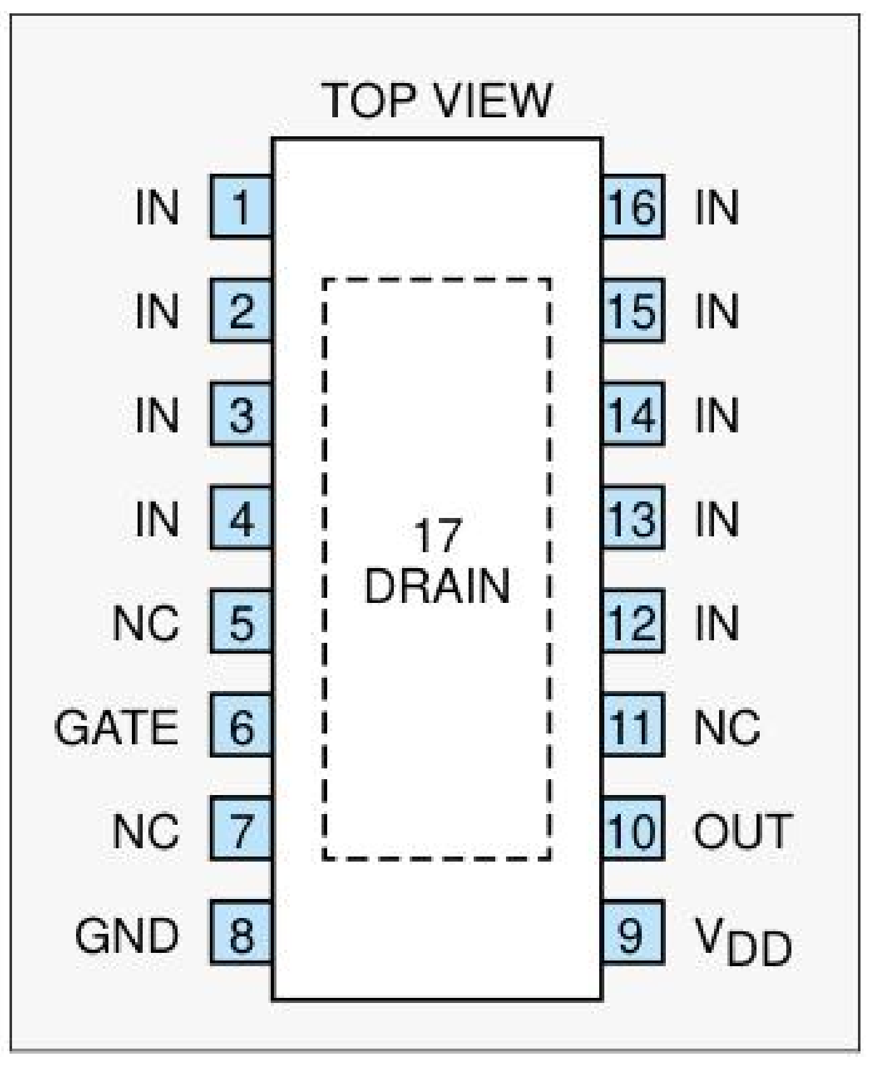


Fig.5. LTC4358 pin configuration for 16-pin TSSOP package. (Based on Analog Devices/LT datasheet)

LTC4358 operation

Before looking at the internal subcircuits of the FLTC4358 in more detail we will simulate its normal operation as LTspice includes a model of the devices as part of the current download. Fig.6 shows an LTspice schematic of a basic diode-OR circuit using the LTC4358. This is similar to the test fixture example provided with LTspice. The simulation ramps the voltages

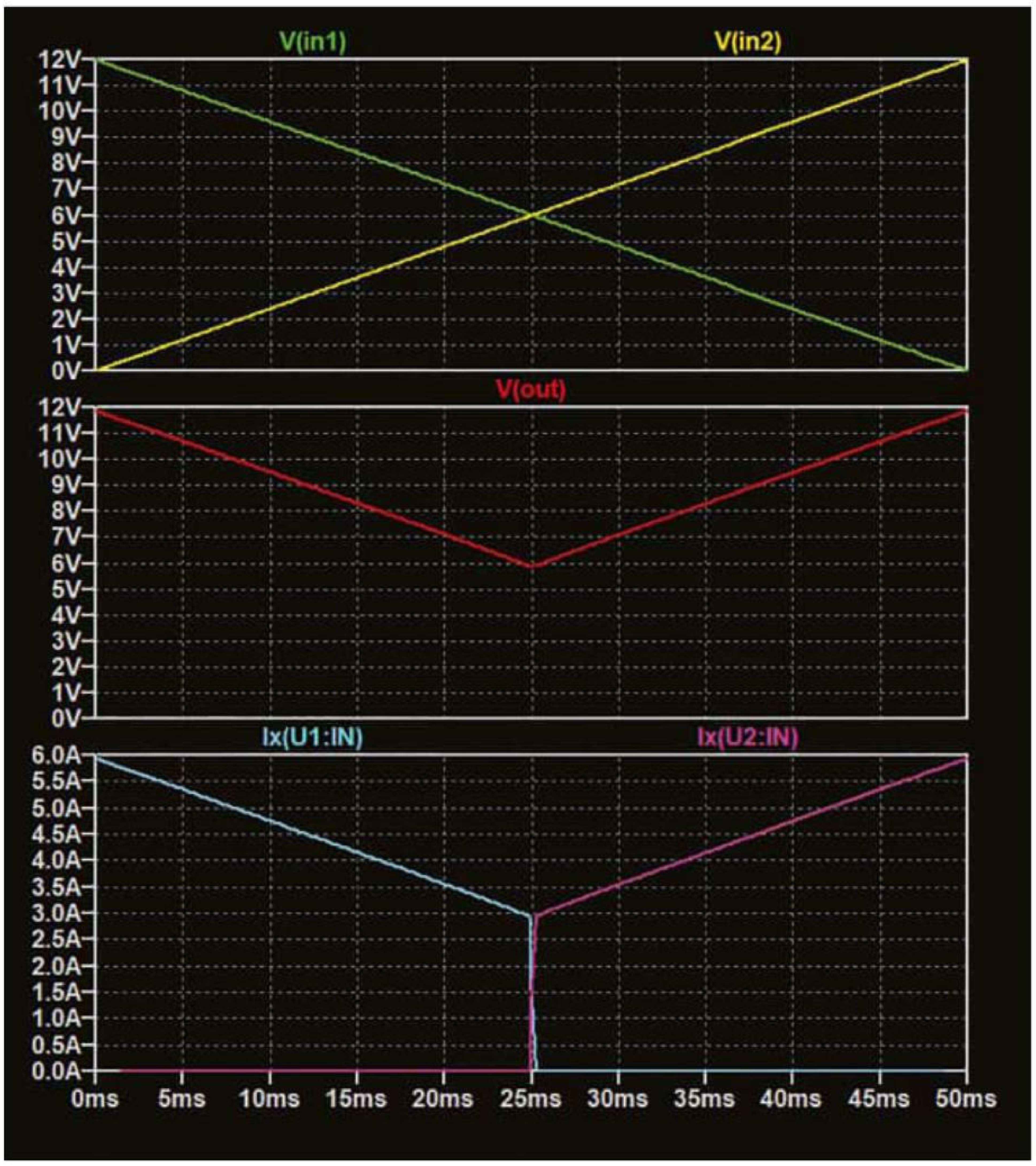


Fig.7. Simulation results from the circuit in Fig.6.

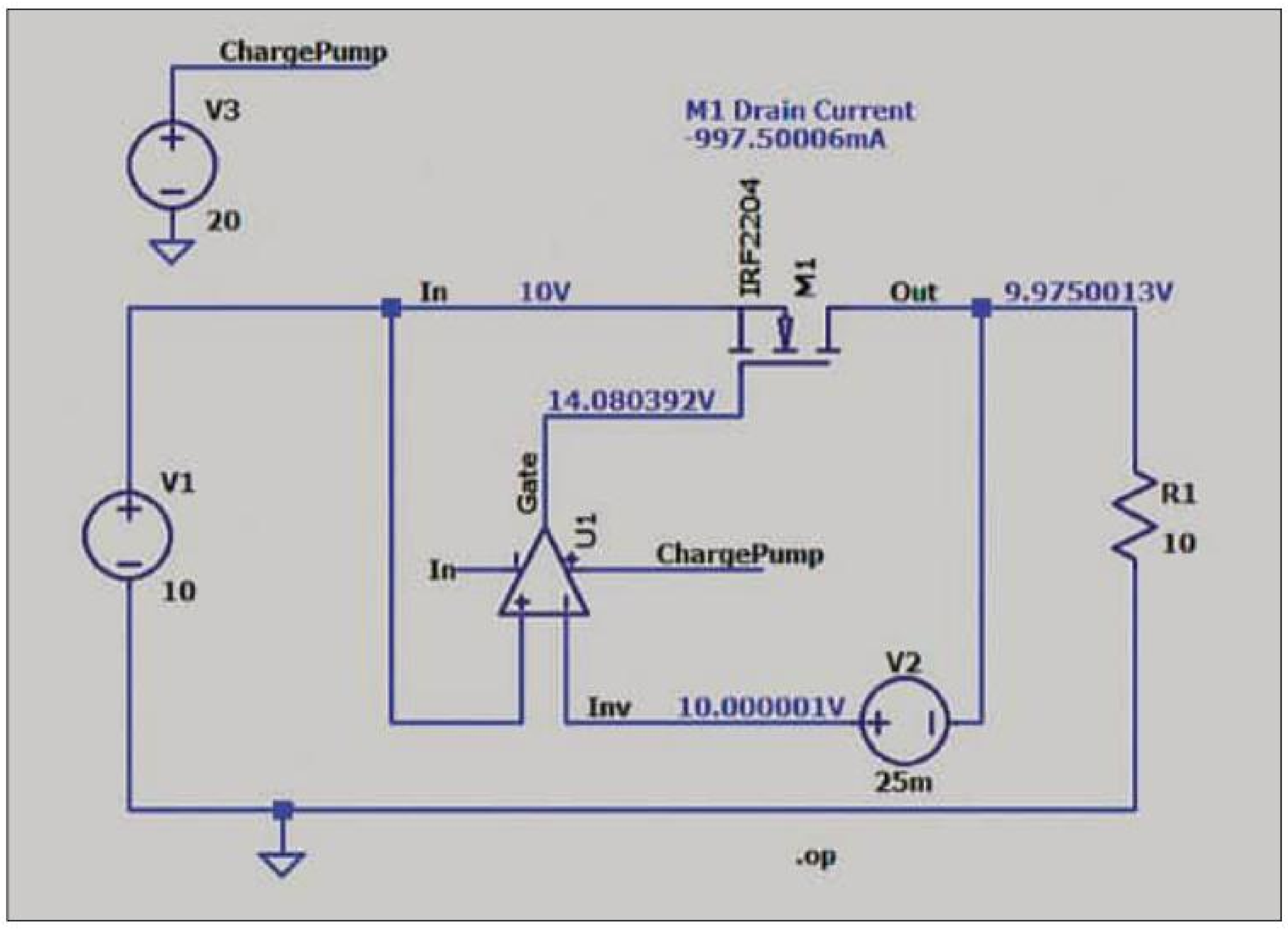


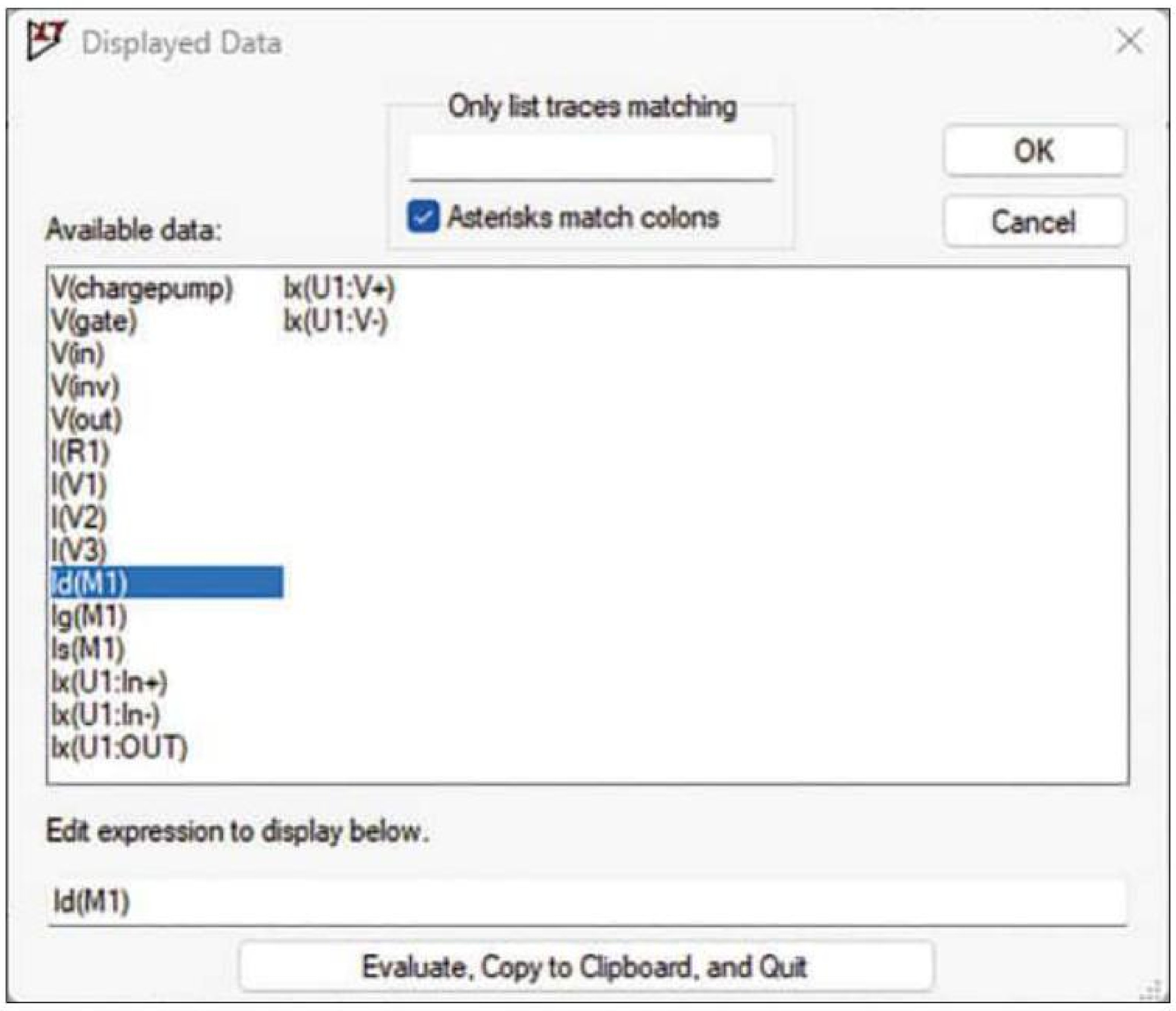
Fig.8. LTspice circuit to model operation of LTC4358 gate amplifier.

on the two inputs between 0 and 12V in opposite directions. The results are shown in Fig.7, where it can be seen that the output voltage (middle plot) is equal to the higher of the two input voltages (upper plot). The current taken from the two inputs is shown in the lower plot – current is taken from the input with the highest voltage and varies in proportion to the supplied voltage because the load is a fixed resistance.

The simulation takes the highest input down to 6V, which is below the minimum specified operating voltage of 9V, but still shows correct operation. Real devices (and/or their simulation models) may operate at lower than specified voltages – however, the manufacturer will not guarantee correct operation or full performance outside operating ranges specified on the datasheet.

Gate amplifier

Now we look at the operation of the Gate Amplifier in conjunction with the MOSFET in more detail. As discussed last month, MOSFETS used in ideal diode circuits are connected so that the body diode (see Fig.4) conducts when the power source input voltage is first connected This provides the initial output voltage and supply for the LTC4358. Once the supply is established, the Gate Amplifier will regulate the voltage across the MOSFET to be 25mV, so for a single device (not necessarily in a diode-OR circuit) the output voltage will be 25mV below the input voltage as long as the input voltage is within the operating range of the device, which is 9V to 26.5V.


Displayed Data
Only list traces matching
☑ Asterisks match colons
OK
Cancel
Evaluate, Copy to Clipboard, and Quit

Available data:

V(chargepump)
V(gate)
V(in)
V(inv)
V(out)
I(R1)
I(V1)
I(V2)
I(V3)
Id(M1)
Ig(M1)
Is(M1)
Ix(U1:In+)
Ix(U1:In-)
Ix(U1:OUT)
Ix(U1:V+)
Ix(U1:V-)

Edit expression to display below.

Id(M1)

Fig.9. Selecting an operating point current to display.

Fig.8 shows an LTspice schematic of the LTC4358 Gate Amplifier subsystem based on the block diagram in Fig.4. The circuit does not attempt to accurately represent the full details of the LTC4358's internal circuitry (which we do not know) but is sufficient to demonstrate principles of operation. The op amp is modelled using LTspice's `UniversalOpAmp2`, which is a generic, semi-ideal model. The MOSFET is an IRF2204, which is a high-current, power MOSFET, but which was not chosen for any very specific reason – this is a simplified model, not a circuit design. Many n-channel MOSFETS will work here but will show different gate voltages depending on their characteristics and are not likely to exactly match the LTC4358's MOSFET (for which we do not have a model). Resistor `R1` represents the load – the circuit that is being supplied via the LTC4358. The charge pump is simply modelled as a voltage source (`V3`) at about twice the source supply (`V1`) voltage.

We need an operating point simulation (`.op` command) to obtain the voltages (and currents) in the circuit. LTspice produces these results as a text file in a pop-up window. For the circuit in Fig.8 we obtain:

```
V(gate):          14.0804          voltage
V(chargepump):    20               voltage
V(in):            10               voltage
V(inv):           10               voltage
V(out):           9.975            voltage
Id(M1):           -0.9975          device_current
Ig(M1):           -6.24878e-009    device_current
Is(M1):           0.9975           device_current
I(R1):            0.9975           device_current
I(V3):            -0.000491457     device_current
I(V2):            1.00026e-008     device_current
I(V1):            -0.997009        device_current
Ix(u1:1):         -1e-008          subckt_current
Ix(u1:2):         -1e-008          subckt_current
Ix(u1:3):         0.000491457      subckt_current
Ix(u1:4):         -0.000491428     subckt_current
Ix(u1:5):         2.61943e-016     subckt_current
```

LTspice operating point labels

It is often more convenient to show the operating point values of interest on the schematic (as in Fig.8). To do this, run the operating point simulation, close the pop-up window and then right-click on a wire on the schematic and choose `Place .op Data Label` from the menu. When a simulation is run again after this the values on the schematic will change to '???' and the pop-up window will appear as before. After closing the window, the numerical values will be displayed on the schematic. As can be seen in Fig.8, the text might take up a fair amount of space and some adjustment of a schematic layout may be required to obtain a clean display of the values.

The above instructions apply to voltages, but displaying operating point currents on the schematic is more tricky and non-obvious. Here's how you do it. Right-click on the schematic background and from the menu select: `Draft > .op Data Label`. Click on the schematic and place the '???' text where you want the data displayed Right-click on the '???' text. In the dialog window that appears (see Fig.9) delete the $ character from the 'expression' box and then click on the data item from the list that you would like to display. In this case `Id(M1)`, the drain current for MOSFET `M1`, is selected. Unlike voltages written next to wires it is not necessarily obvious what the numerical value represents when looking at the schematic, so adding comment text ('Aa' button on the menu bar) next to the value may be a good idea (as has been done for the MOSFET current in Fig.8). The current value for `Id(M1)` is reported as negative because it is defined as the current *into* the drain, but it is actually flowing *out* of the drain.

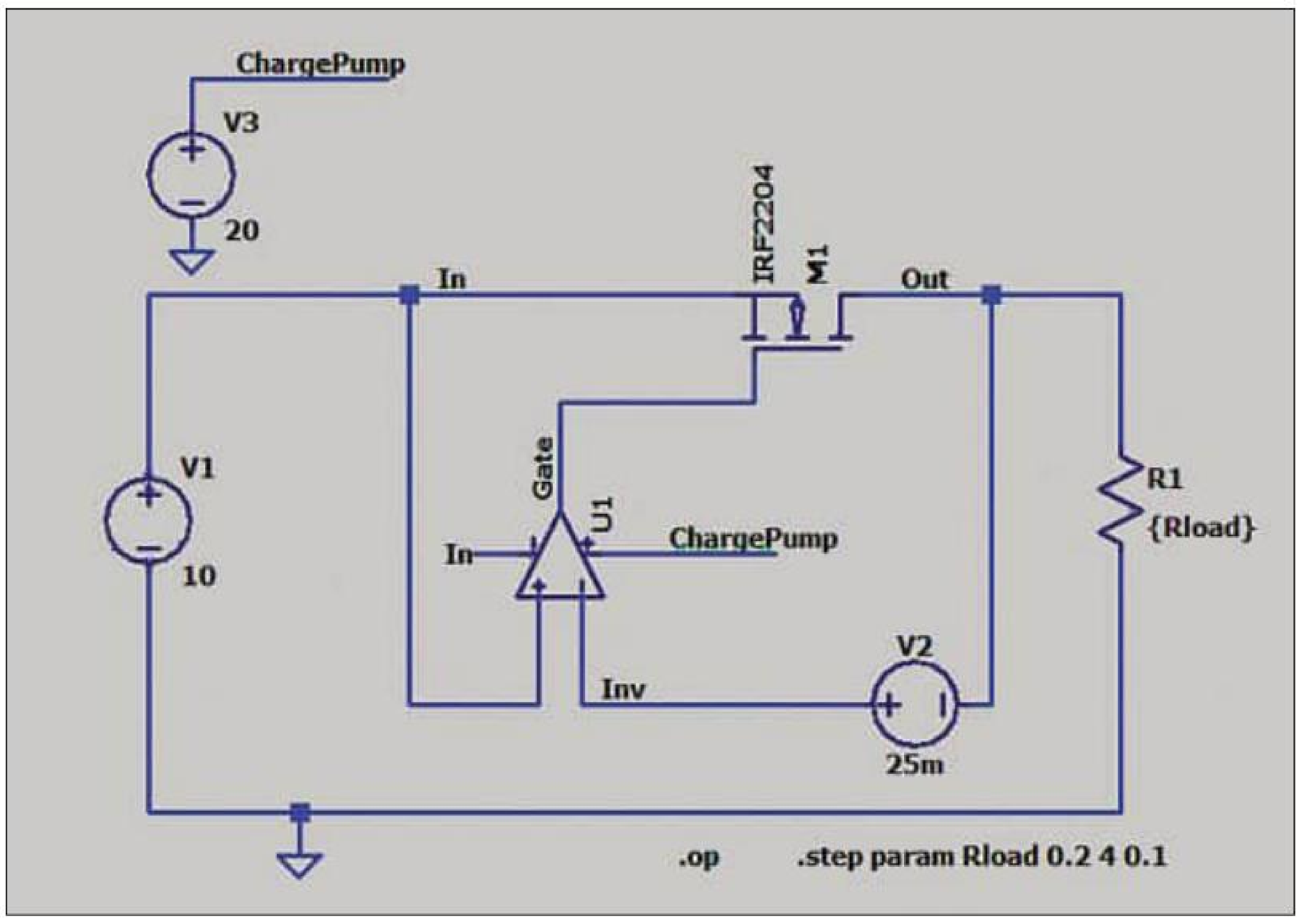


Fig.10. LTspice simulation of load resistance sweep for LTC4358 gate amplifier subsystem model.

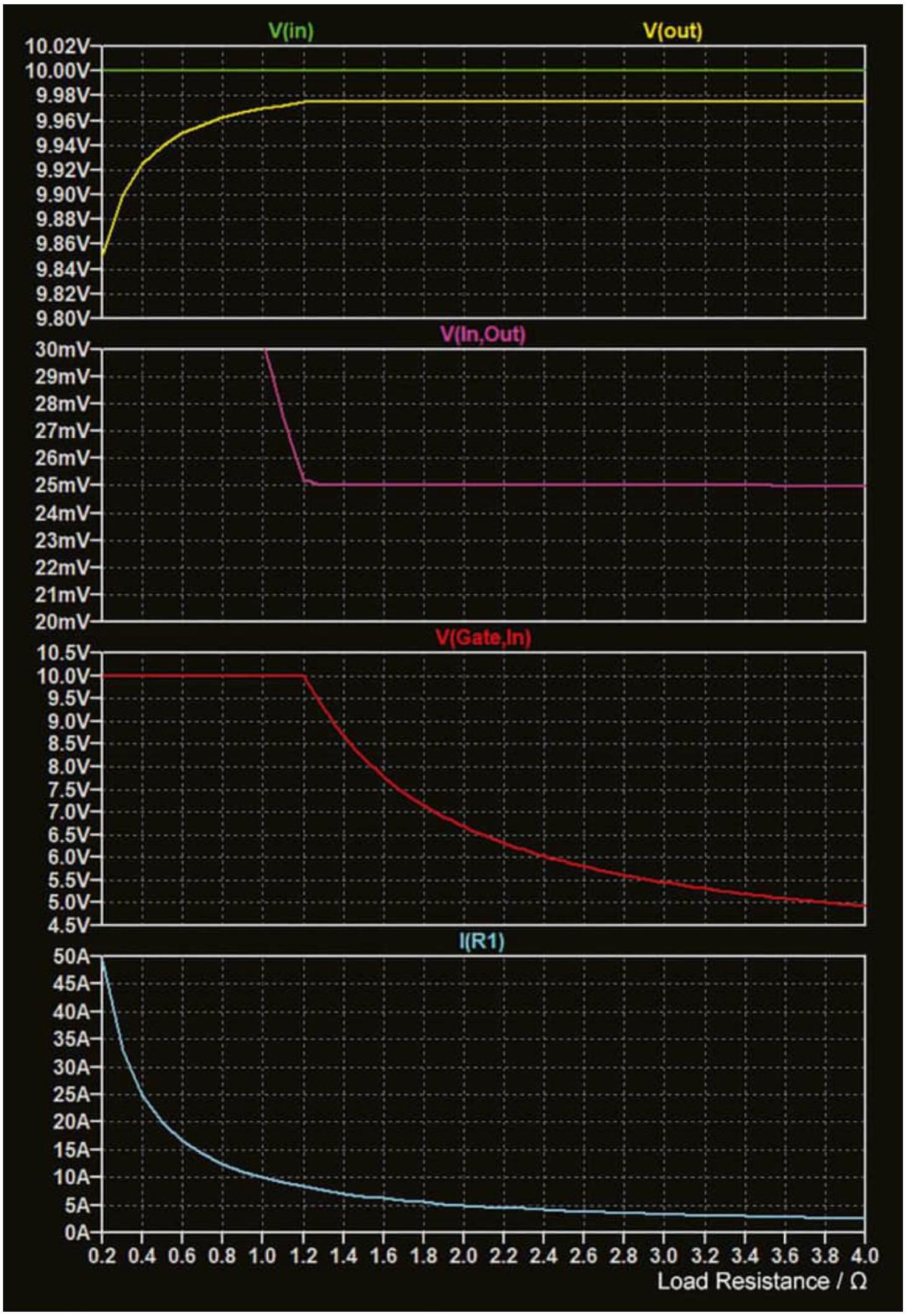


Fig.11. Results from simulation of circuit in Fig.10

Gate amplifier simulation

Looking at the results in Fig.8, we see that the source supply (V_{In} from `V1`) is 10V. The charge pump supply is at 20V ($V_{\text{ChargePump}}$ from `V3`). Thus, the Gate Amplifier (`U1`) operates on a 10V supply – the difference between V_{In} on its negative supply and $V_{\text{ChargePump}}$ on its positive supply. The Gate Amplifier is wired as a control loop – the negative feedback from the LTC4358's output (node `Out`) to its inverting input (node `Inv`) tries to maintain zero volts between the amplifier's inputs. The non-inverting input is at V_{In} (10V), so the inverting input voltage (V_{inv}) will also be at this voltage, or very close to it when the Gate Amplifier is actively controlling the circuit (as seen on Fig.8).

Controlling V_{inv} to be equal to V_{In} means that V_{out} will be at V_{In} – 25mV by virtue of the 25mV source (`V2`). This is the same as saying the voltage across the MOSFET (source to drain) is controlled to be 25mV. The value of V_{out} is equal to $R_1 I_L$, where I_L is the load current through load (`R1`). Current into the Gate Amplifier input is very small, so we can assume I_L is equal to the current through the MOSFET. Thus, the output voltage is controlled by the MOSFET current, which is in turn controlled by its gate-source voltage (V_{GS}). The Gate Amplifier sets V_{GS} on the MOSFET to whatever value is required for a 25mV drop between source and drain, in this case it is about 14.1V (with respect to ground), so V_{GS} = 4.1V. This value would be different if a different MOSFET was used, and will change under different conditions. The specific value of V_{GS} does not matter as long as it is within the range that the Gate Amplifier can output and does not exceed the MOSFET's operating range.

We can simulate the behaviour of the LTC4358 Gate Amplifier under varying load conditions using a parametric sweep. The specific values seen here do not necessarily match the actual device – this is a simplified, illustrative model with different component parameters. The setup for this simulation is shown in Fig.10. The schematic is the same as Fig.8, except that we are not showing the current and voltage values and have replaced the fixed 10Ω value of `R1` with the parameter `{Rload}`. The simulation varies `R1` from 0.2Ω to 4Ω in 0.1Ω steps, as defined using the .step command. Relatively low `Rload` values are used to highlight the limit of regulating the MOSFET voltage drop. The results are plotted as circuit operating point voltages and currents against load resistance, as shown in Fig.11.

For relatively high load resistance values (on the right-hand side of Fig.11, for values above about 1.2Ω), the circuit is able to regulate the voltage across the MOSFET. The top plane shows both the fixed 10V input voltage, and the output voltage, which is also more or less constant for larger load resistance values. The second pane shows the difference between the input and output

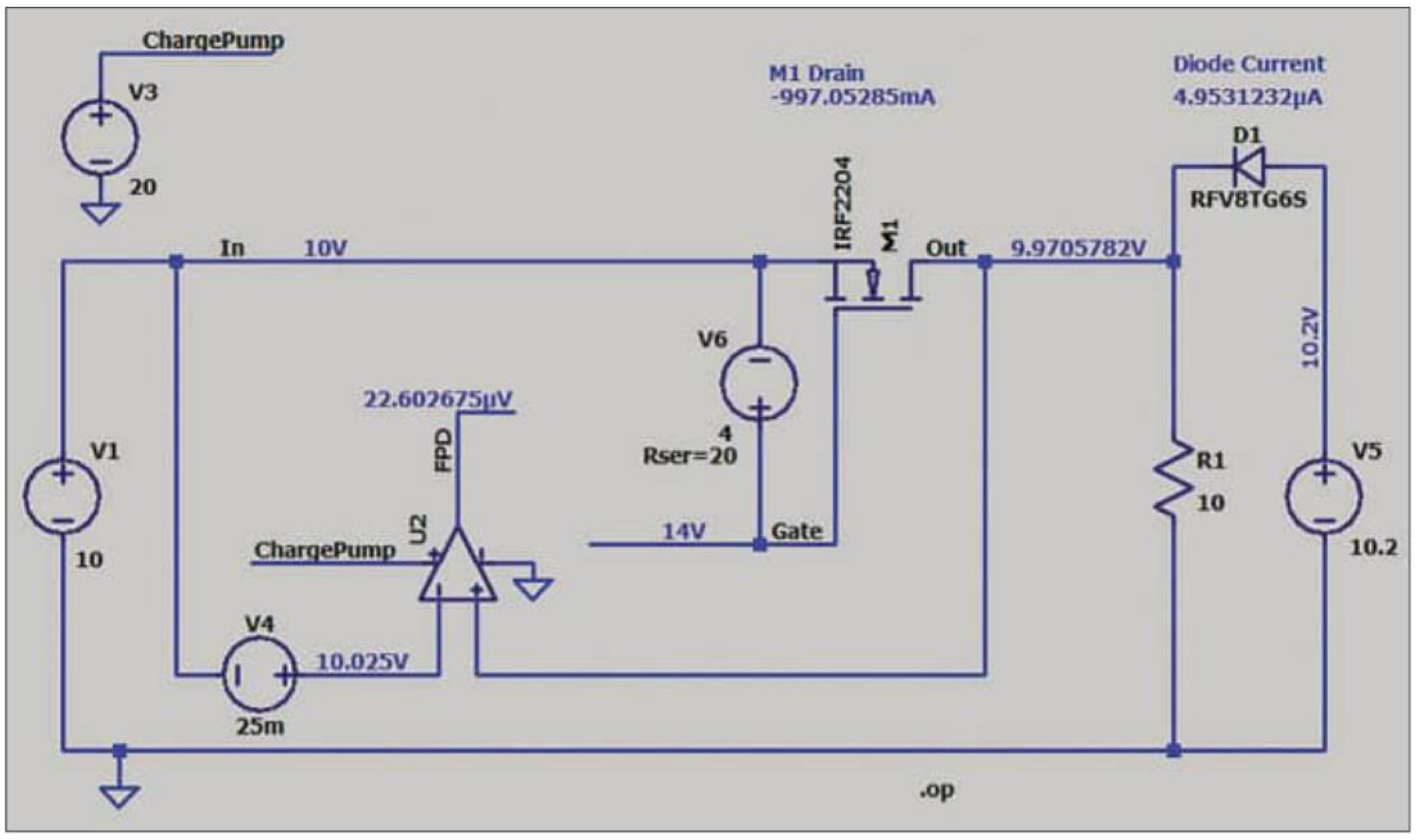

ChargePump
V3
20
M1 Drain
-997.05285mA
Diode Current
4.9531232µA
D1
RFV8TG6S
IRF2204
M1
In
10V
Out
9.9705782V
V6
10.2V
22.602675µV
4
Rser=20
V1
FPD
R1
10
V5
10
U2
14V
Gate
10.2
ChargePump
V4
10.025V
25m
.op

Fig.12. LTspice circuit to model operation of LTC4358 FPD comparator – normal operation scenario.

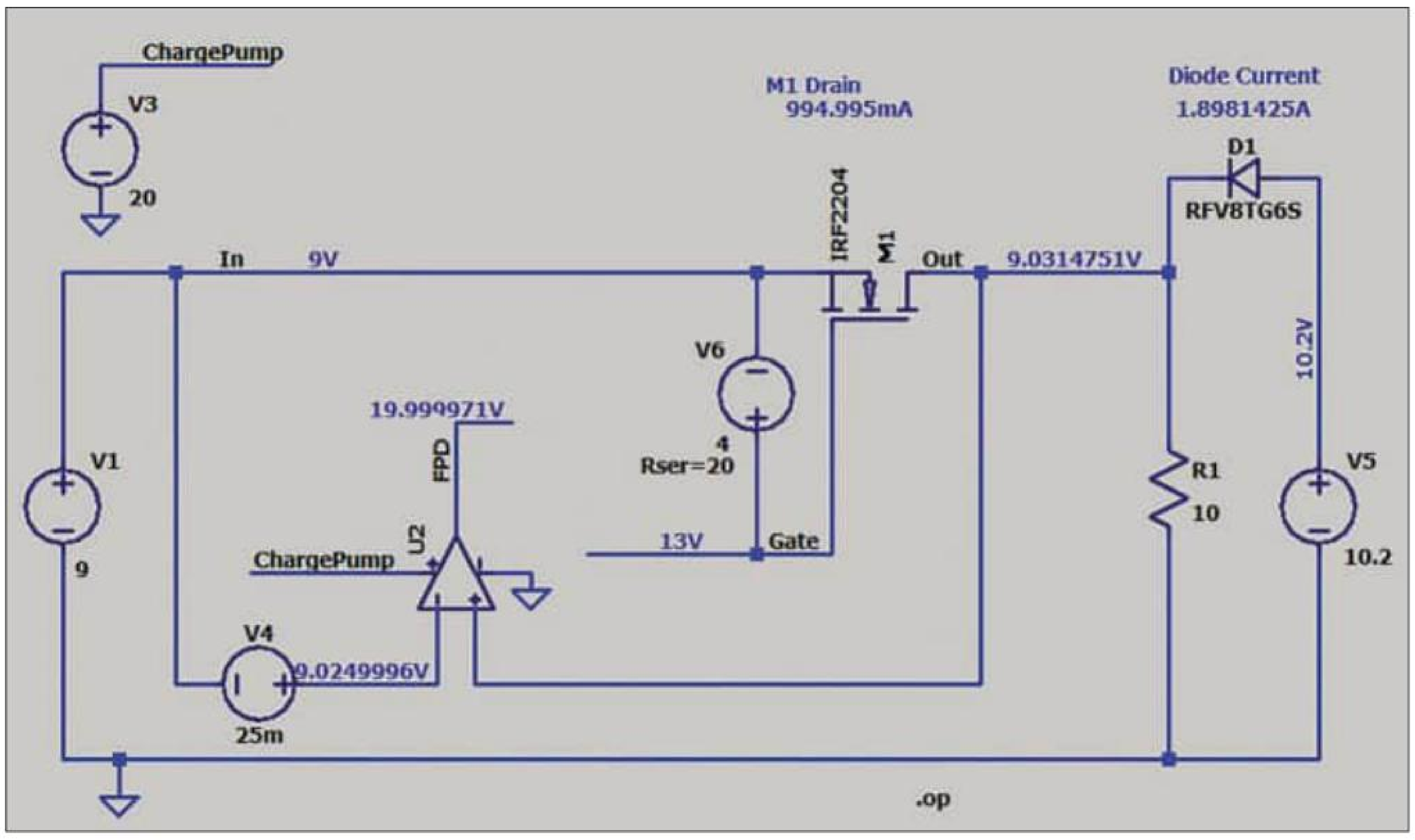

ChargePump
V3
20
M1 Drain
994.995mA
Diode Current
1.8981425A
D1
RFV8TG6S
IRF2204
M1
In
9V
Out
9.0314751V
V6
10.2V
19.999971V
4
Rser=20
V1
FPD
R1
10
V5
9
U2
13V
Gate
10.2
ChargePump
V4
9.0249996V
25m
.op

Fig.13. LTspice circuit to model operation of LTC4358 FPD comparator – reverse-current scenario.

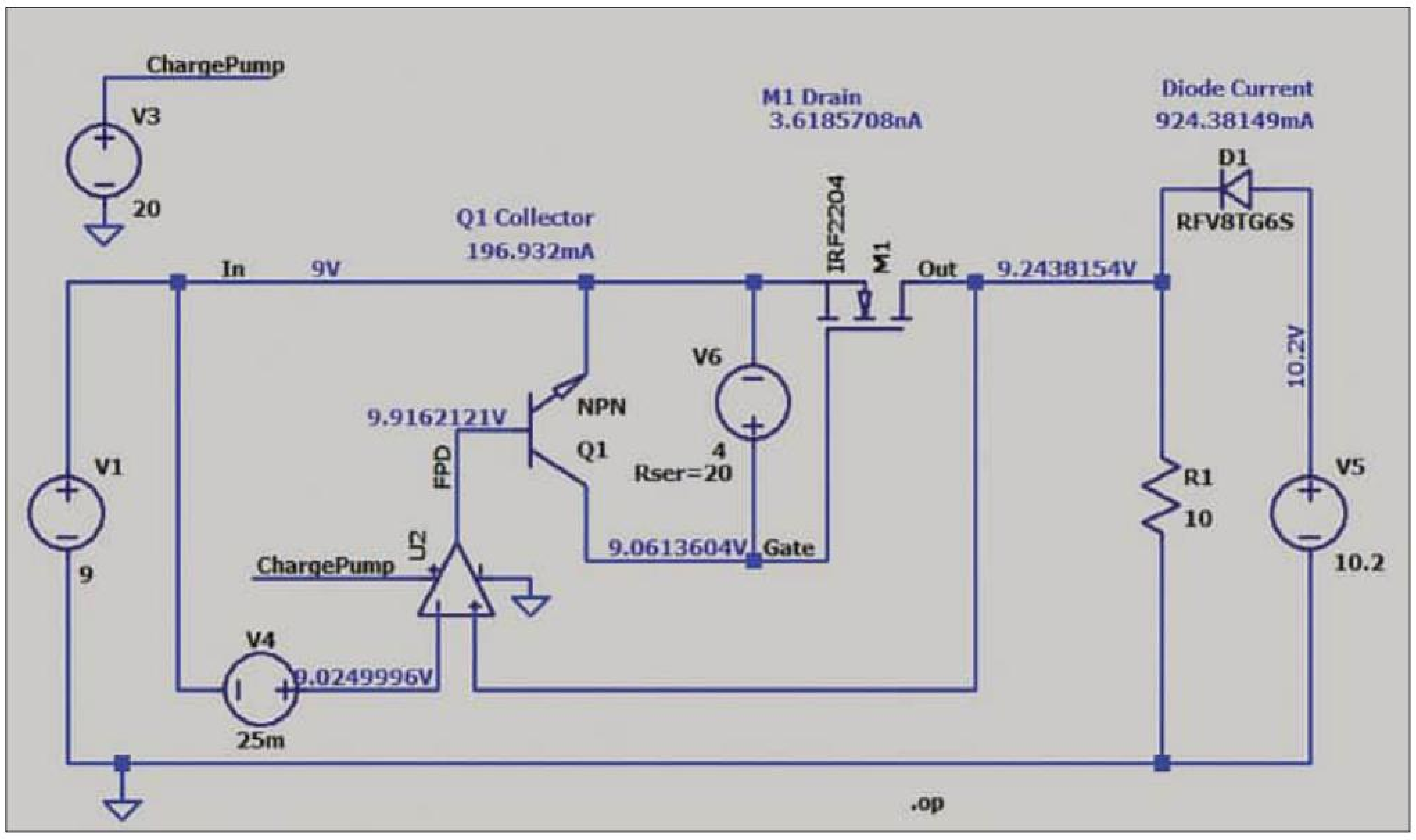

ChargePump
V3
20
M1 Drain
3.6185708nA
Diode Current
924.38149mA
D1
RFV8TG6S
Q1 Collector
196.932mA
IRF2204
M1
In
9V
Out
9.2438154V
V6
NPN
10.2V
9.9162121V
Q1
V1
FPD
4
Rser=20
R1
10
V5
9
U2
9.0613604V
Gate
10.2
ChargePump
V4
9.0249996V
25m
.op

Fig.14. LTspice circuit to model operation of LTC4358 FPD comparator. Potential reverse-current detection used to switch off MOSFET.

voltages, which for larger resistance values is constant at 25mV, as expected from the discussion above.

Over the load range for which the MOSFET drop is regulated (above about 1.2Ω) the gate voltage varies with varying load resistance. As the load resistance decreases, the MOSFET V_{GS}, which is shown in the third pane, has to increase to maintain the drain-source voltage at 25mV. The maximum value of V_{GS} is limited by the power supply to the Gate Amplifier, which is 10V relative to V_{In} in this example. For load resistances below 1.2Ω the gate voltage would have to exceed 10V, which it is unable to do, so the regulation is lost. The load current (bottom plane) varies with load resistance and is equal to V_{out}/R_{load} as would be expected (from Ohm's law).

FPD comparator

Fig.12 shows an LTspice schematic of the LTC4358 FPD Comparator subsystem based on the block diagram in Fig.4. This version of the schematic does not have the output of the comparator connected to the MOSFET so that we can observe the MOSFET reverse-current situation which the comparator is used to overcome. To simplify the simulation, we have replaced the Gate Amplifier with a fixed gate-source voltage of 4V provided by `V6`. In order to observe a reverse-current situation, we need another voltage source at the output. In a real circuit this could come from another LTC4358 in a diode-OR circuit or a capacitor charged to the output voltage. Here we use a voltage source (`V5`) and diode (`D1`) as a simple model for another LTC4358 and its source supply.

The situation shown in Fig.12 is similar to that in Fig.8. The `V1` source is providing the power to the load resistor. The additional supply (`V5`) is effectively disconnected because the diode (`D1`) is not conducting (only microamps flowing through it). The FPD Comparator is set up to switch to a logic 1 output at a voltage 25mV *above* V_{In}. This will not occur when the LTC4358's internal MOSFET is conducting (the voltage on V_{out} is 25mV *below* V_{In} under these conditions). Therefore, in the scenario in Fig.12 the output of the FPD Comparator is at logic zero (close to ground voltage) and (if it was connected) it would not affect the operation of the device.

Fig.13 shows the same circuit as Fig.12 with the source supply (`V1`) reduced to 9V. This means that the additional supply (`V5`) is providing current to the load (`R1`) via diode `D1`. The 4V V_{GS} is still applied to the MOSFET, so it still conducts, but current flows in the opposite direction (note the change in sign of the `M1` drain current compared with Fig.12). A current of about 1A is flowing from the additional supply to the source supply of the LTC4358 via

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

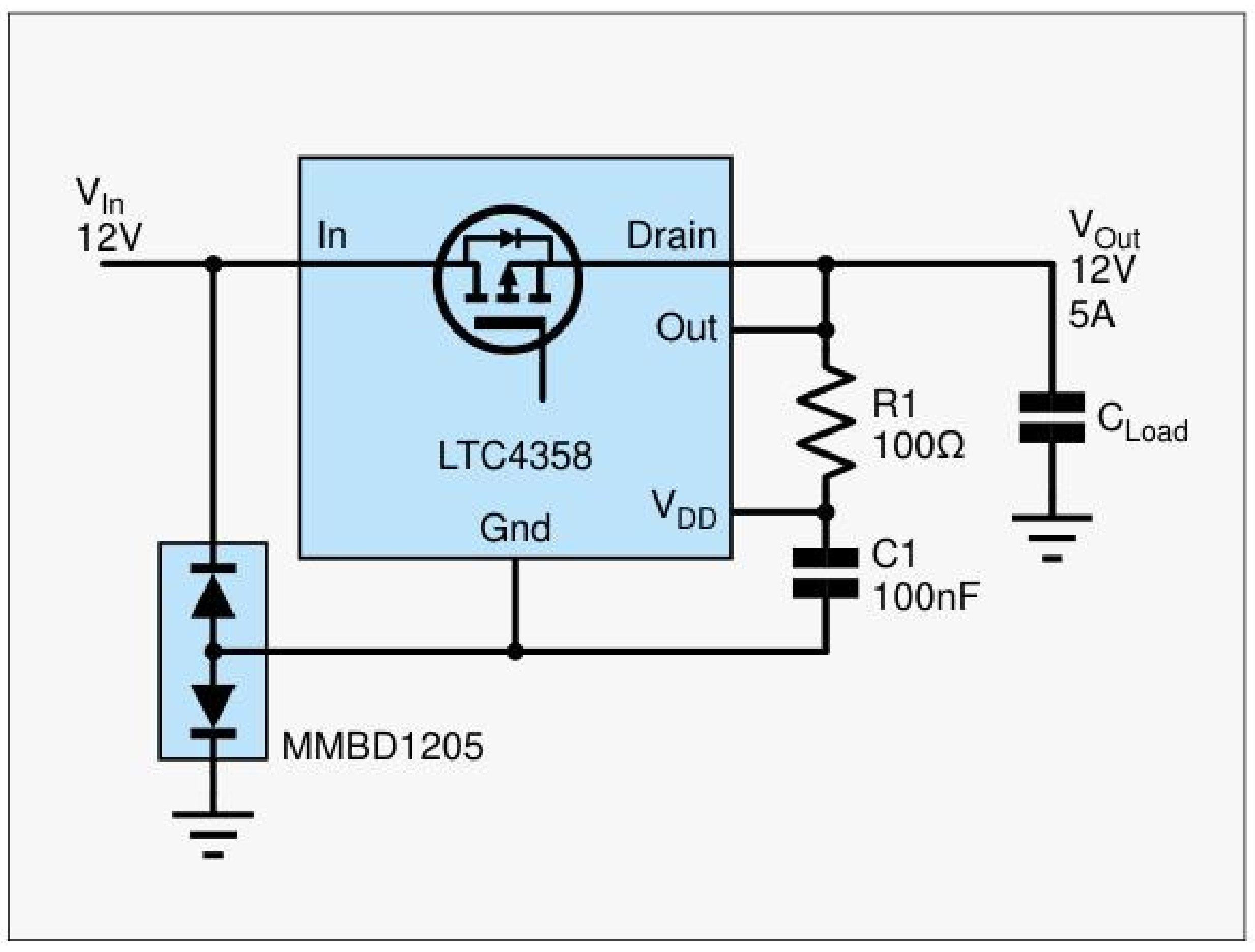


Fig.15. (above) Providing reverse-input protection for the LTC4358. (Based on Analog Devices/LT datasheet)

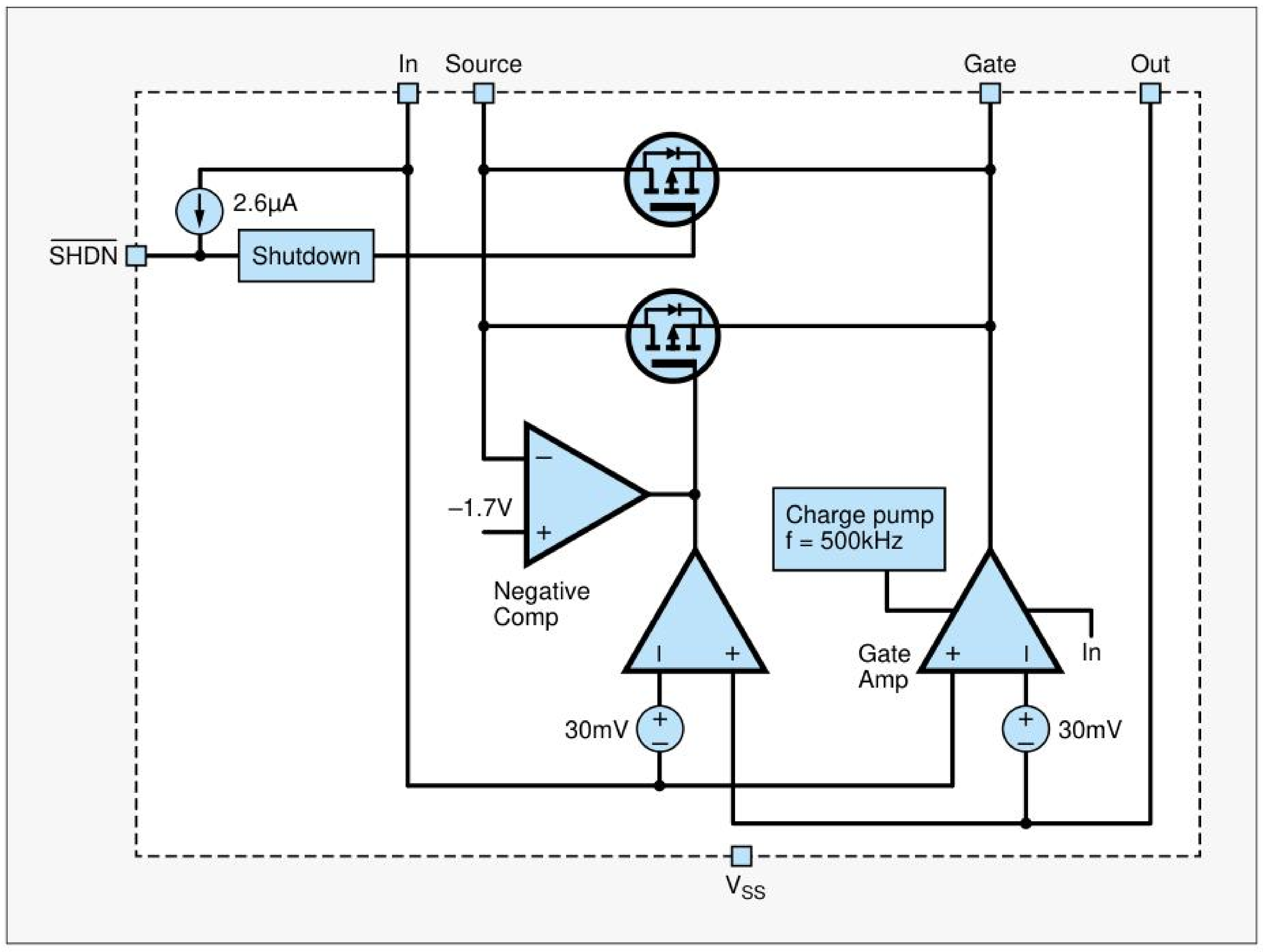


Fig.16. (right) The LTC4358 includes negative-input detection and an external shutdown control pin. (Based on Analog Devices/LT datasheet)

the MOSFET. This is the reverse current condition that must be avoided to provide correct ideal diode behaviour. In this scenario the output voltage (V_{out}) is above the input (V_{In}) by about 31mV. This is greater than the 25mV-above-V_{In} threshold set for the comparator, so its output is a logic one (equal to its positive supply voltage).

Reverse current protection

The above two scenarios show that the comparator output indicates the direction of current flow through the MOSFET. Its output can therefore be used to switch off the MOSFET under reverse-current conditions. This is achieved using an NPN transistor connected between the gate and source of the MOSFET (see Fig.4). When the comparator output is logic 1 the NPN transistor switched on, effectively shorting the gate of the MOSFET to its source and reducing the gate-source voltage below threshold. This switches the MOSFET off and prevents reverse current flow.

Fig.14 shows the same circuit as in Fig.12 and Fig.13, but with the NPN transistor (`Q1`) added. The voltage sources are configured in the same way as shown in Fig.13 – the reverse-current scenario. The switching off of the MOSFET by the FPD comparator via `Q1` can be seen – the MOSFET's drain-source current is effectively zero (nanoamps). The current from the additional supply via `D1` is reduced as it is now only providing the load current in `R1`. The current in `Q1` shown in Fig.14 is not meant to be representative of the actual LTC4358 circuit – it is mainly determined by the source resistance value of `V6`, which prevents ideal-source behaviour resulting in totally unrealistic currents.

The above simulations show the principles of operation of the LTC4358 in regulating the MOSFET voltage drop and preventing reverse currents. In a real circuit the reverse current condition is caused by the drop in the source supply voltage to the LTC4358. The additional supply (`V5` and `D1` in the above examples) will be due to either capacitors connected to the LTC4358 output or other supplies in a diode-OR arrangement. The drop in source supply may occur very rapidly. The LTC4358's datasheet states that the ideal diode is turned off within 500ns of a reversal, preventing the reverse current rising to a damaging level and minimising any disturbance on the output.

Reverse input protection

As was noted earlier, the LTC4358 does not provide reverse-input protection. The datasheet suggests the circuit shown in Fig.15 to provide protection. The RC circuit (R1 and C1) hold up the supply to the LTC4358 during supply disturbances, which helps it deliver fast switch-off. Other devices similar to the LTC4358 do provide more reverse protection, for example the LTC4359 has a comparator to detect reverse-input conditions and switch off the external MOSFET (see block diagram Fig.16). The external MOSFET is not shown in Fig.16, the MOSFETs in the block diagram are used in the same way as the NPN transistor in Fig.4 to switch of the external power MOSFET. The LTC4359 also features an external pin which can be used to switch off the device.

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Max's Cool Beans

By Max the Magnificent

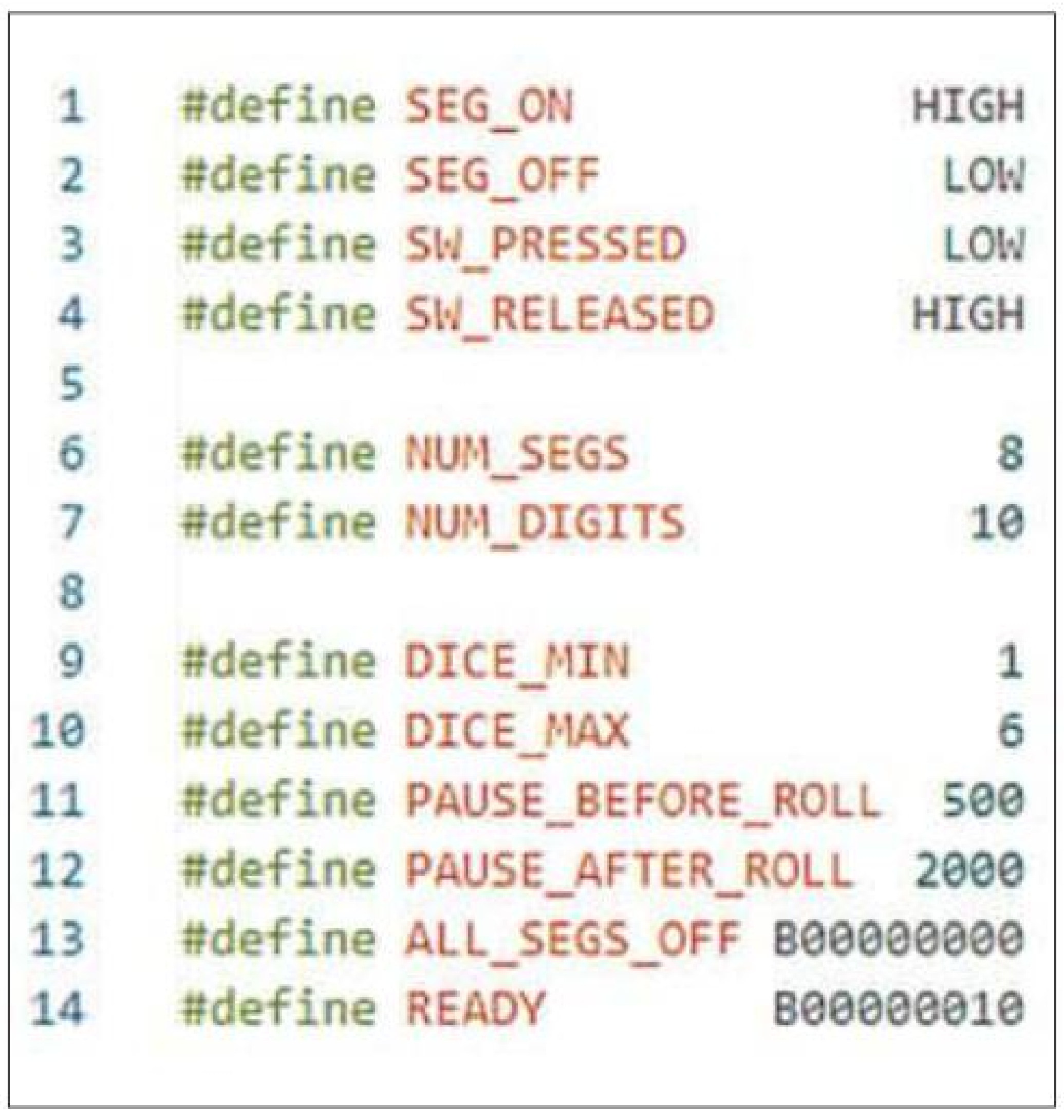
Arduino Bootcamp – Part 8

Are you ready for some fun? I know I am. As I sit here poised to start this column, sweat is careening down my cranium and dripping into my eyes. The problem is – much like the Norwegian Blue in Monty Python's classic *Dead Parrot Sketch* – the air conditioning system in our home is, at present, an ex-air conditioning system. Since I currently hang my hat in Huntsville, Alabama in the US, the temperature in the house is 86°F (30°C) and the humidity is off the scale. There's a nice man who has been working on the system all day. He says it should be up and running shortly (what he doesn't say is that he's poised to relieve me of a big chunk of my hard-earned moolah, to which I say, 'thank goodness for credit cards').

Rolling the dice

At the end of my previous column, I left you with some homework. This was to think of at least three different applications we can implement with our setup so far, which involves a breadboard with two buttons, a piezoelectric buzzer, and our 7-segment display, all connected to an Arduino Uno microcontroller development board.

On the off-chance you are new to the *PE* community (in which case, 'Hello, it's great to meet you!') and you're wondering what we're waffling about, you can download a copy of our current breadboard layout showing both switches, our buzzer, and our 7-segment display – along with various pull-up and current-limiting resistors – coupled with the connections to our Arduino Uno (file **CB-Aug23-01.pdf**). As usual, all of the files mentioned in this column are available from the August 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**



```
1   #define SEG_ON               HIGH
2   #define SEG_OFF               LOW
3   #define SW_PRESSED            LOW
4   #define SW_RELEASED          HIGH
5
6   #define NUM_SEGS                8
7   #define NUM_DIGITS             10
8
9   #define DICE_MIN                1
10  #define DICE_MAX                6
11  #define PAUSE_BEFORE_ROLL     500
12  #define PAUSE_AFTER_ROLL     2000
13  #define ALL_SEGS_OFF    B00000000
14  #define READY           B00000010
```

Listing 1. Definitions.

Also in my previous column, I said that I'd start the ball rolling by suggesting one possible application, which would be to implement a form of electronic dice. Every time we press one of our buttons, our program will display a random number from 1 to 6 on our 7-segment display.

Preparing to rock and roll

What we are going to do is create an entirely new program (or 'sketch' in the vernacular of the Arduino community). Having said this, we will retain some of the elements of our earlier experiments. You can peruse and ponder a copy of this new program (file **CB-Aug23-02.txt**). We're not going to go through the entire program here, but I think it's worth skimming through the highlights as follows. We'll start with some definitions (Listing 1).

In Lines 1 and 2 we define `SEG_ON` and `SEG_OFF` as being `HIGH` and `LOW` respectively. As you may recall, we discussed the relationships between 0 and 1, 0V and 5V, `LOW` and `HIGH`, and `false` and `true` in an earlier column (*PE*, March 2023). Since we are using a common-cathode display (which we introduced in *PE*, February 2023), the light-emitting diodes (LEDs) forming the segments on our display turn on when presented with 5V signals and turn off when presented with 0V values.

In Lines 3 and 4 we define `SW_PRESSED` and `SW_RELEASED` as being `LOW` and `HIGH`, respectively. Although this may seem counterintuitive at first, this is because we are using normally open (NO) momentary pushbutton switches. In our implementation, the signals to the Arduino are pulled-up to 5V by means of pull-up resistors (Fig.1). It's only when a switch is pressed that it connects its corresponding signal to ground (GND, 0V).

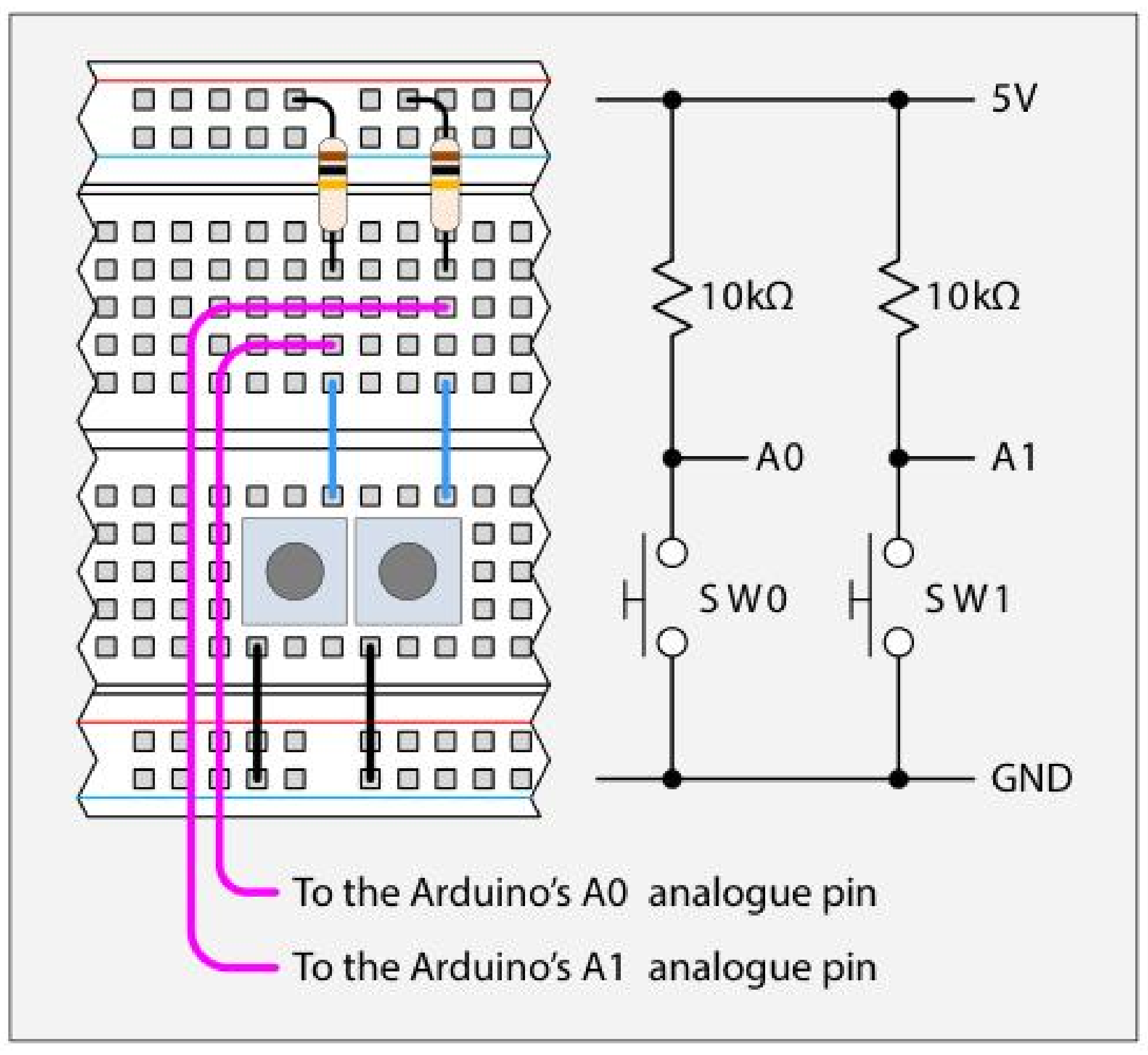

5V
10kΩ
10kΩ
A0
A1
SW0
SW1
GND
To the Arduino's A0 analogue pin
To the Arduino's A1 analogue pin

Fig.1. Two pushbutton switches.

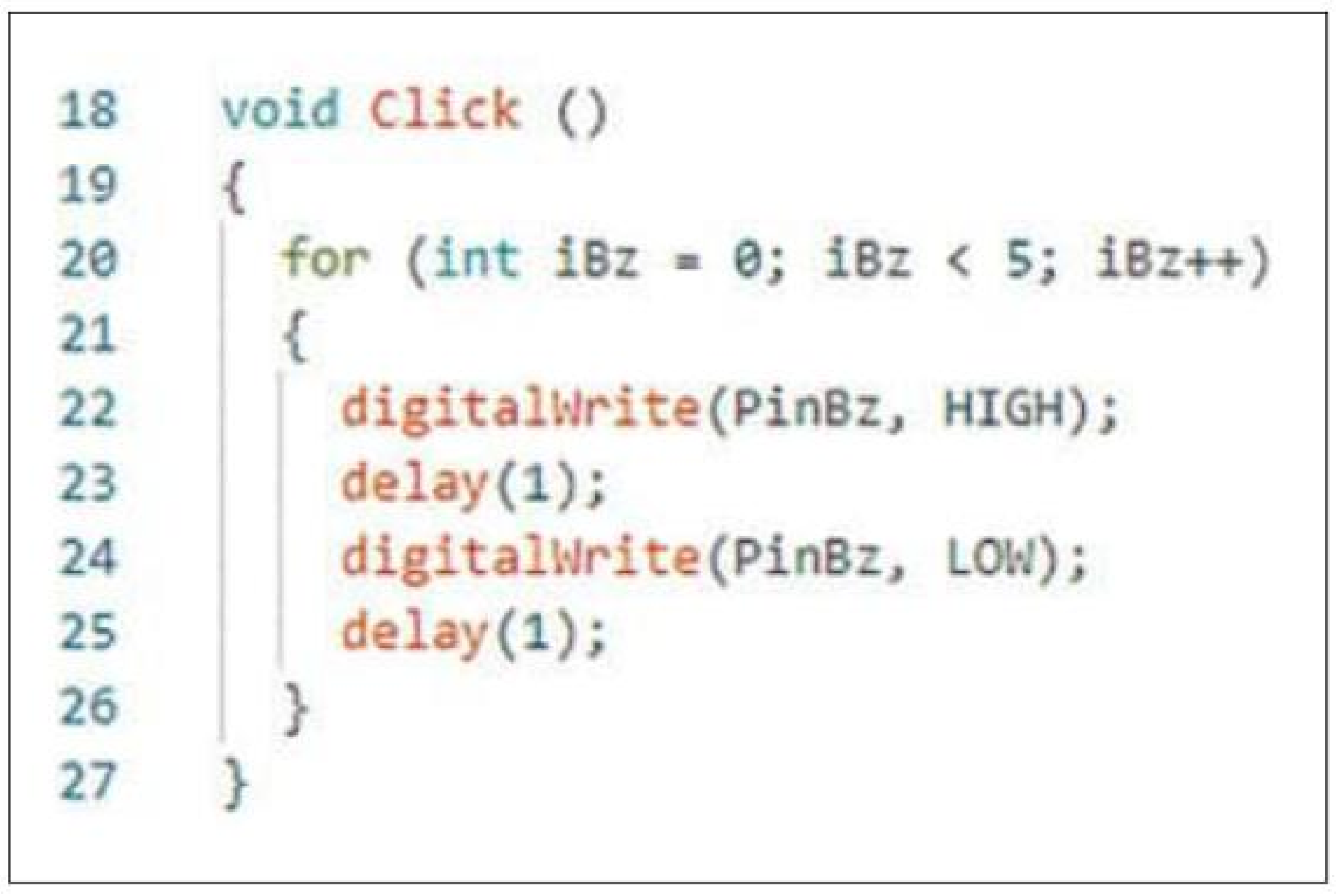
For the purposes of this experiment, we are going to employ only switch `SW0`, which we will use to inform our program when we wish to 'roll' our virtual dice.

In Line 6 we define `NUM_SEGS` (the number of segments on the display, including the decimal point) as being 8. In Line 7 we define `NUM_DIGITS` (the number of digits we wish to display) as being 10. This is because we have ten digits in our decimal number system: 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9.

You may be wondering why we are planning on defining all ten digits when, for the purposes of this program, we are planning on displaying only the digits 1 through 6. There are two reasons. First, this will make things easier if we ever wish to modify our program to reflect 7, 8, 9 or 10-sided dice… and yes, there are such beasts – see: **www.thediceshoponline.com**

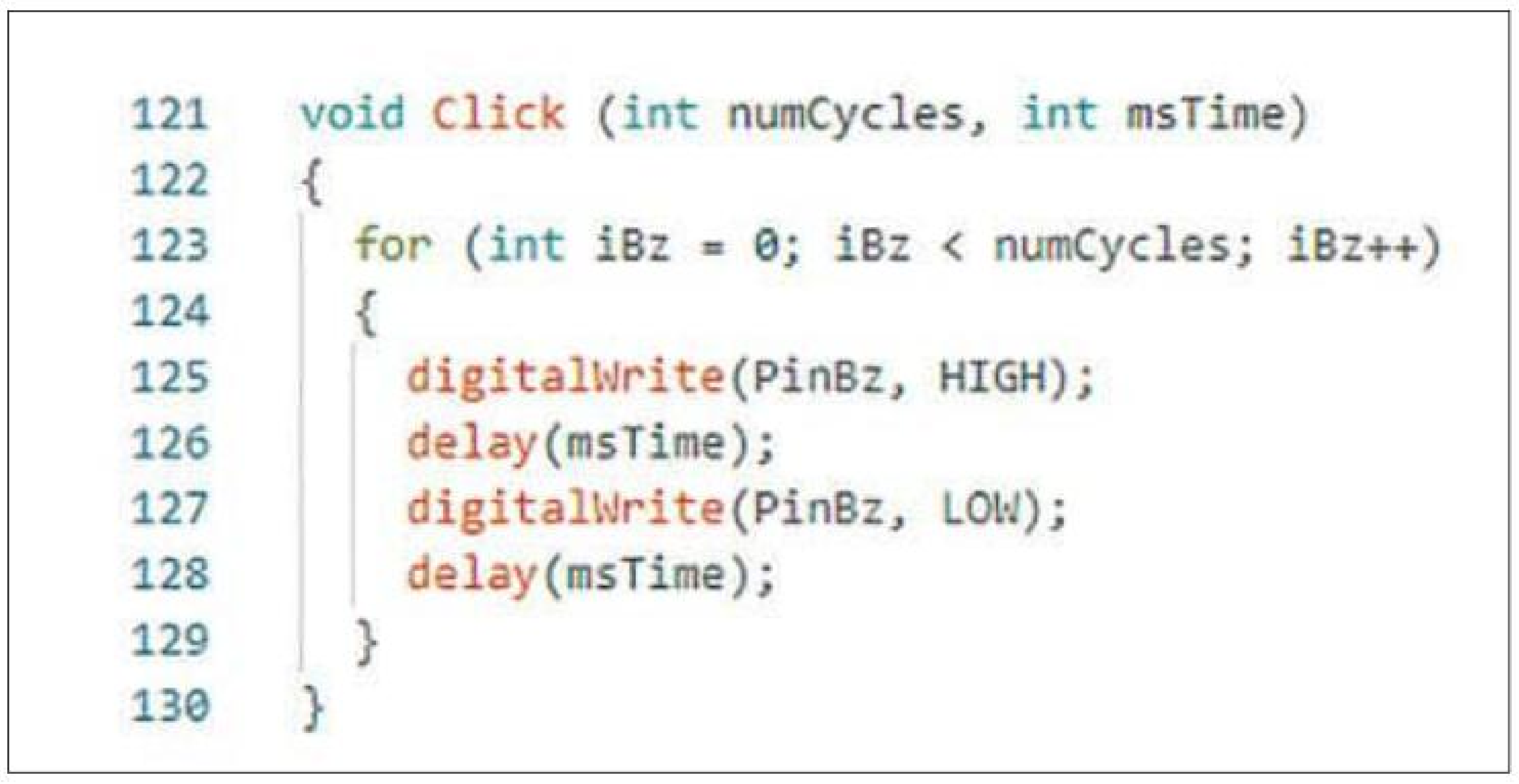
Second, for reasons we don't wish to delve into here, modifying our code to define only the digits 1 through 6 would be more trouble than it's worth.

In Lines 9 and 10 we define the minimum and maximum values we wish to receive when we 'roll' our virtual dice. In Lines 11 and 12 we define two delays we wish to use before and after the dice is rolled. In Line 13 we define a bit pattern corresponding to all the segments being off. In Line 14 we define a bit pattern corresponding to only the middle segment (like a minus sign) being on to reflect a 'ready' condition, indicating that the program is ready for the user to press the switch.



```
void Click ()
{
  for (int iBz = 0; iBz < 5; iBz++)
  {
    digitalWrite(PinBz, HIGH);
    delay(1);
    digitalWrite(PinBz, LOW);
    delay(1);
  }
}
```

Listing 2. (left) Our original `Click()` function.



```
void Click (int numCycles, int msTime)
{
  for (int iBz = 0; iBz < numCycles; iBz++)
  {
    digitalWrite(PinBz, HIGH);
    delay(msTime);
    digitalWrite(PinBz, LOW);
    delay(msTime);
  }
}
```

Listing 3. (right) Our upgraded `Click()` function.

We won't bother going through the rest of the variable declarations because we've seen them all before, like our `PinsSegs[]` and `DigitSegs[]` arrays. Similarly, we don't need to revisit our `DisplaySegs()` function, which accepts a bit-pattern in the form of an 8-bit byte and uses this pattern to turn the corresponding display segments on or off. (All of these were first introduced in *PE*, April 2023 and we've been using them ever since.)

One thing we do need to consider is our `Click()` function, which we've been using to drive our piezoelectric buzzer to make an exaggerated 'click' sound when we press our pushbutton switches. The original version of this function (which we introduced in *PE*, June 2023) is shown in Listing 2.

I was just about to start throwing around terms like 'square wave' and 'mark-space ratio' when I remembered that that these might be new to some readers, so let's briefly introduce these concepts as follows.

Our `Click()` function generates a 'square wave,' which is a periodic waveform whose amplitude alternates at a steady frequency between fixed minimum and maximum values. In this case, the term 'mark-space ratio' refers to the ratio of the pulse being high (the 'mark') and low (the 'space'). The time taken to complete a complete cycle (ie, the time between successive pulses) is known as the 'period,' which equals the mark *plus* the space (Fig.2).

Since it's a ratio, the mark-space ratio is, of course, unitless. In this example, we've divided each cycle into four equal portions. If the pulse is high for one of these portions and low for the other three, then its mark-space ratio is 1:3 or 25%:75% (Fig.2a). By comparison, if the pulse is low for one portion and high for the other three, then its mark-space ratio is 3:1 or 75%:25% (Fig.2c). And, of course, if the pulse is high for two periods and low for two periods, then its mark-space ratio is 2:2 or 50%:50%. This is the same as saying 1:1; that is, a perfect square wave whose mark-space ratio is 'unity' (Fig.2b).

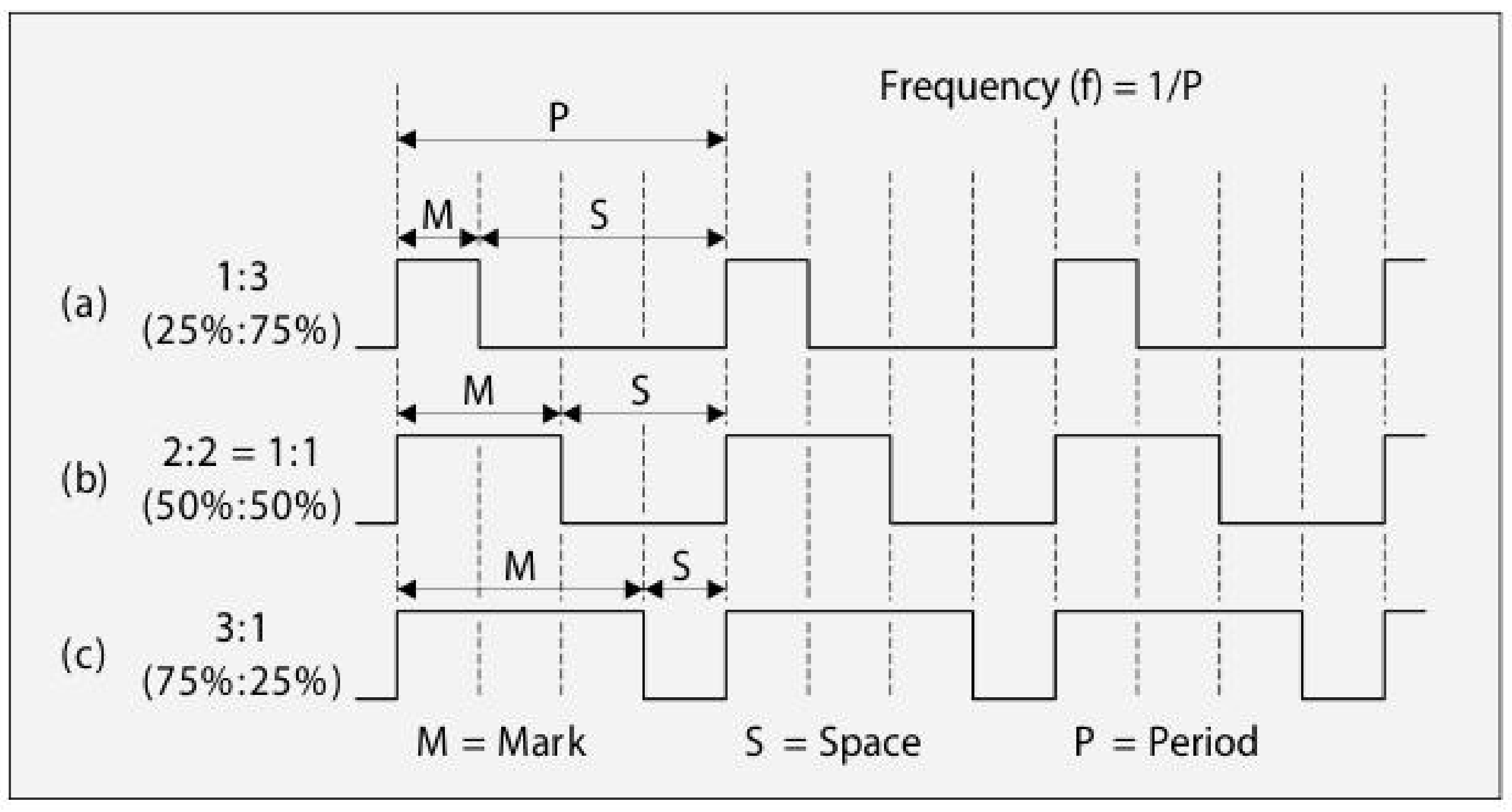


Fig.2. Square waves and mark-space ratios.

In the original incarnation of our `Click()` function, we hard-coded the number of cycles (5). We also hard-coded the durations of the signal's mark and space times as 1ms (millisecond) each, which means the period (*P*) is 2ms, which is 0.002s (seconds). Since frequency (the number of cycles per second) is calculated as 1/*P*, this means the frequency of our signal is 1/0.002s = 500Hz. As an aside, 'Hz' stands for 'hertz.' This unit is named after Heinrich Rudolf Hertz (1857–1894), who was the first person to provide conclusive proof of the existence of electromagnetic waves.

We arrived at the values used in our original `Click()` function by trial-and-error. At that time, I invited you to play around with them to experiment with different sounds. For the purposes of our rolling the dice program, we are going to modify this function, as illustrated in Listing 3.

All we've done is parameterise the number of cycles and the time we use for both the mark and space delays. The reason we've done this is to allow us to generate different sounds to indicate different things.

We're almost there

We are so close to actually rolling our virtual dice that I can almost taste it (it's yummy!). Let's take a look at our new `loop()` function, as shown in Listing 4.

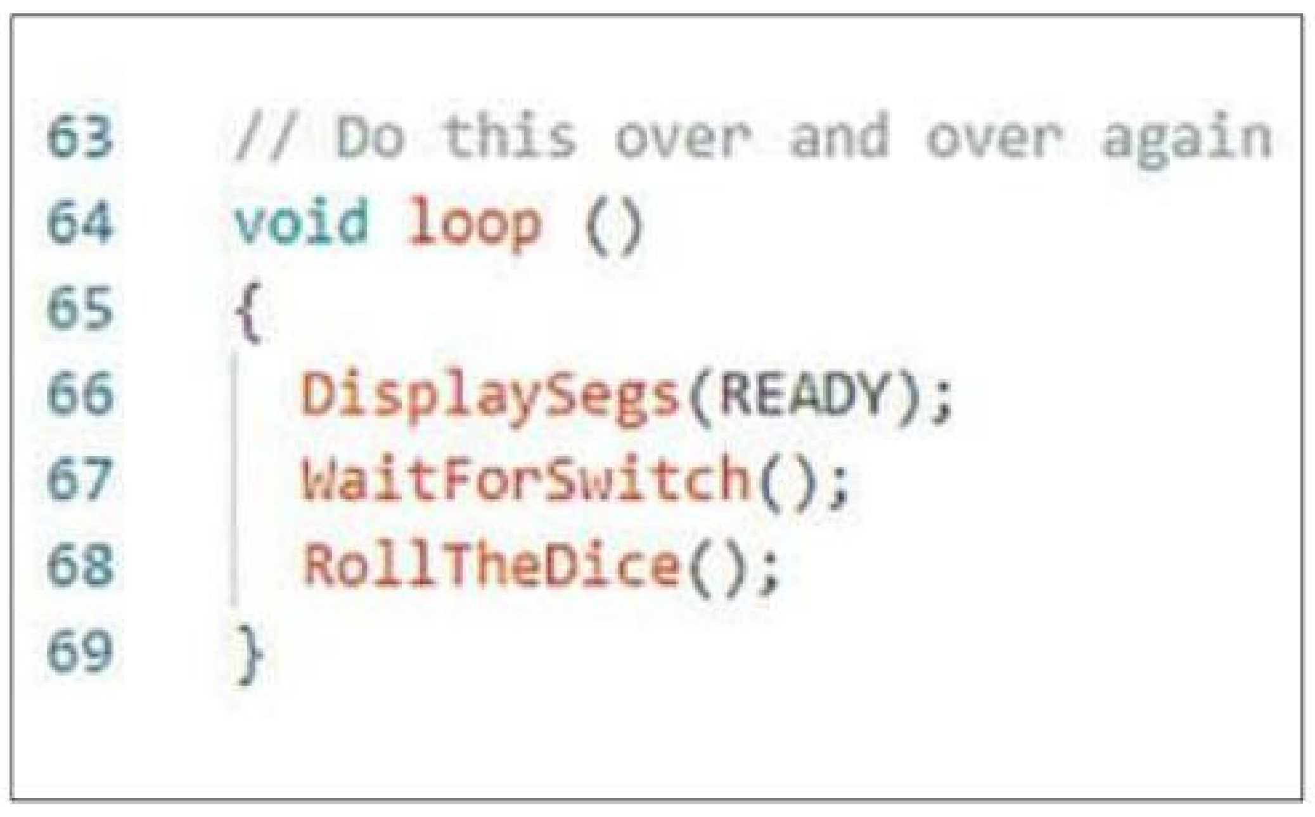
As we see, we loop around doing three things. First, we call our `DisplaySegs()` function, passing it the `READY` bit pattern we previously defined to activate the middle horizontal LED in our 7-segment display. Remember that we're using this to indicate that the program is ready for the user to press the button.

Next, we call a new `WaitForSwitch()` function, after which we call a new `RollTheDice()` function. Can you guess what these functions do!?

Let's start with the `WaitForSwitch()` function, as illustrated in Listing 5. In Lines 77 through 80 we use a `do-while` loop to cycle around waiting for the switch to be pressed (we introduced this form of loop statement in *PE*, March 2023).

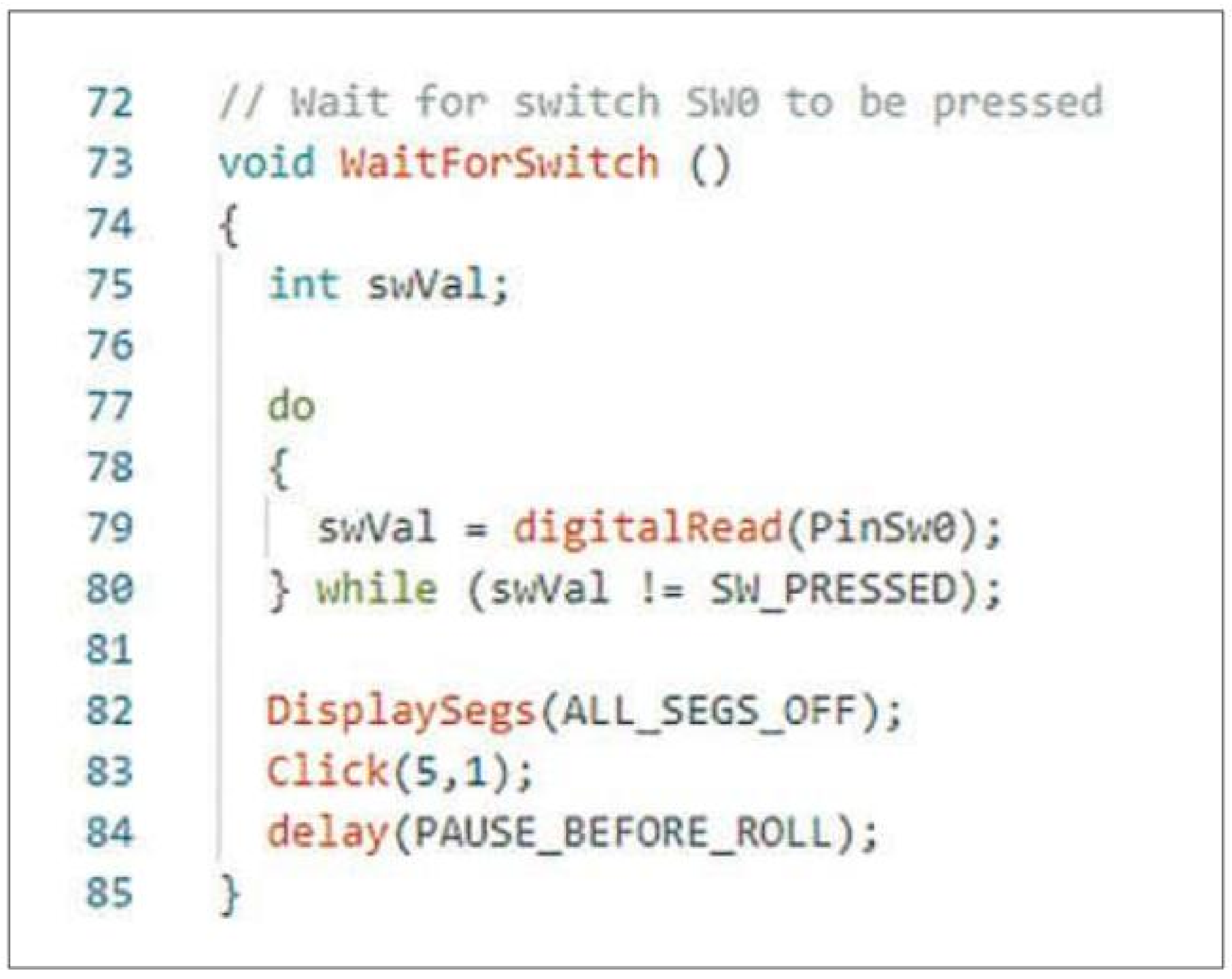
In Line 82 we call our `DisplaySegs()` function to turn all the segments off. In Line 83 we call our `Click()` function with parameters of 5 (the number of cycles) and 1 (the time to be used for the mark and space delays). These parameters will result in the same 'click' sound we heard before. Finally, in Line 84, we pause for a moment to allow the user's eyes to register that something is about to happen.

Last, but certainly not least, we come to our `RollTheDice()` function, as



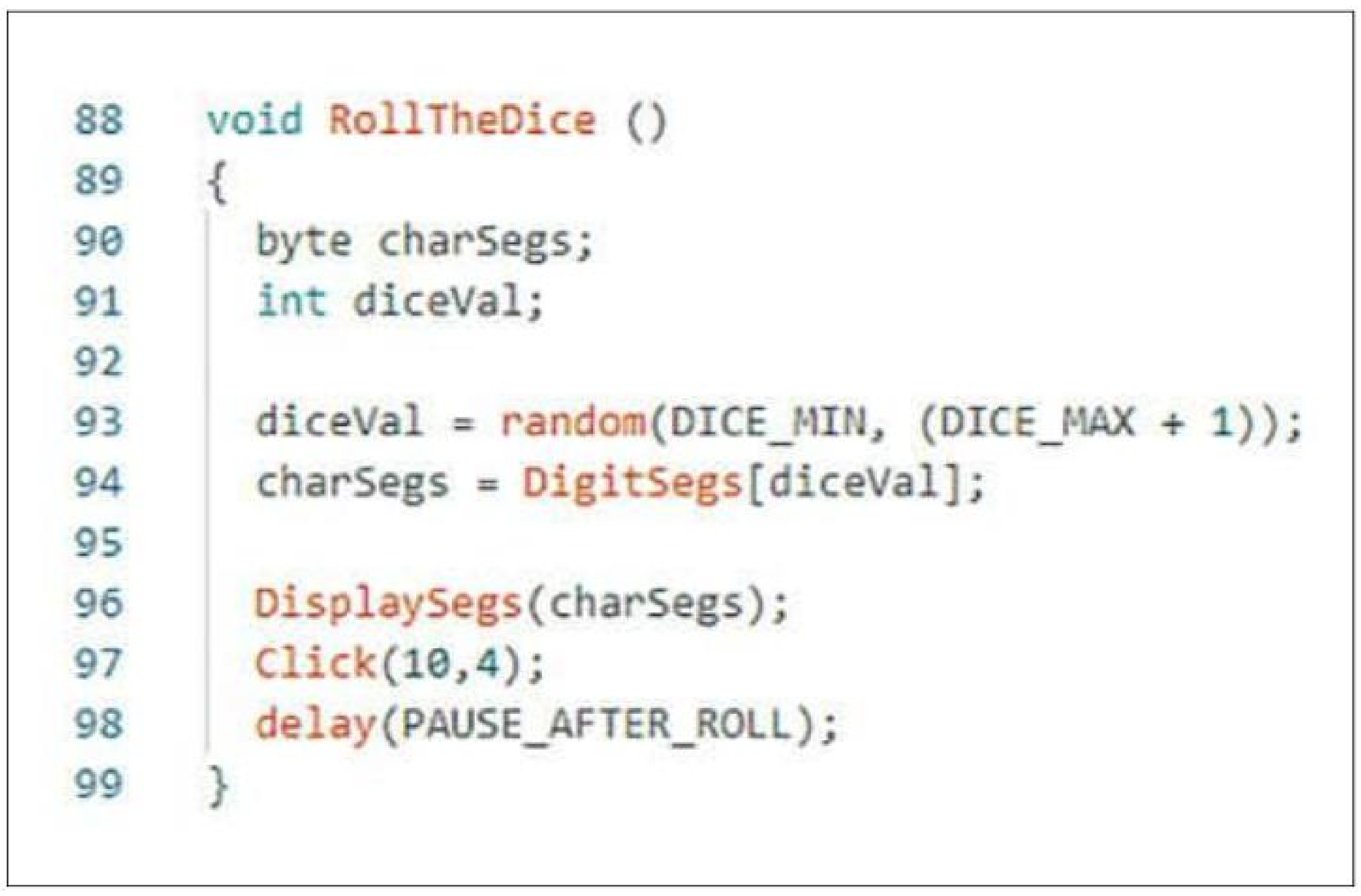
```
// Do this over and over again
void loop ()
{
  DisplaySegs(READY);
  WaitForSwitch();
  RollTheDice();
}
```

Listing 4. Our new `loop()` function.



```
72  // Wait for switch SW0 to be pressed
73  void WaitForSwitch ()
74  {
75    int swVal;
76
77    do
78    {
79      swVal = digitalRead(PinSw0);
80    } while (swVal != SW_PRESSED);
81
82    DisplaySegs(ALL_SEGS_OFF);
83    Click(5,1);
84    delay(PAUSE_BEFORE_ROLL);
85  }
```

Listing 5. Wait for the switch to be pressed.



```
88   void RollTheDice ()
89   {
90     byte charSegs;
91     int diceVal;
92
93     diceVal = random(DICE_MIN, (DICE_MAX + 1));
94     charSegs = DigitSegs[diceVal];
95
96     DisplaySegs(charSegs);
97     Click(10,4);
98     delay(PAUSE_AFTER_ROLL);
99   }
```

Listing 6. Roll the dice and display the result.

illustrated in Listing 6. In Line 93 we generate our random number. We introduced the `random()` function in earlier columns (*PE*, February and March 2023), but it's worth reminding ourselves that this generates a random integer constrained by the lower bound (minimum) and upper bound (maximum) values we provide. The main point to remember is that the lower bound value is inclusive (will be included in the possible generated values) while the upper bound is exclusive (will be excluded from the possible generated values).

All this explains why, although we defined `DICE_MIN` as 1 and `DICE_MAX` as 6, when we call the `random()` function, we set the upper bound value to (`DICE_MAX + 1`). This means that we are essentially calling `random(1,7)`, which will return a random value between 1 and 6. This takes a bit of wrapping one's brain around, but it's not too bad.

In Line 94, we use our newly generated random number to retrieve the corresponding bit pattern to display that value on the 7-segment display.

In Line 96 we call our `DisplaySegs()` function to turn the various segments on and off. In Line 97 we call our `Click()` function with parameters of 10 (the number of cycles) and 4 (the time to be used for the mark and space delays). These parameters will result in a different sound to the one we heard before. Finally, in Line 98, we pause to allow the user to observe the result from rolling the dice. Once this delay times out, we return control to the main `loop()` function and do it all again.

Points to ponder

Before we actually run our new program, there are a couple of points that are well worth pondering. For example, we know that when we activate or deactivate switches, their contacts can 'bounce,' making and breaking connection anywhere from 1 to 100+ times before settling into their new state. We spent a lot of time coming up with a solution to this switch bounce problem in *PE*, June 2023, but we haven't included any of this in our new program. Why not?

Well, from our previous discussions, we know that we are assuming that all bouncing has stopped after 8ms. In the case of our new program, as soon as we see the first transition on our switch, we commence the process of rolling the dice and displaying the result for two seconds before returning to look at the switch, by which time we know it will have stopped bouncing.

When we generated random numbers in previous programs, we included an extra test to ensure that the new number wasn't the same as the previous value. Why didn't we do that this time? Well, we're trying to emulate a dice, and when we roll a physical dice it can certainly come up with the same number multiple times in succession.

What will happen if, when we press the switch, we hold it and don't release it? We should be able to work this out simply by looking at our code. Is this what we want to happen? Personally, I couldn't care less because it's not something I expect the user to do. More importantly, nothing radical will happen if the user does decide to do this. On the other hand, if we were designing a system for real-world use that we wished to be foolproof, we should consider, document, and account for every possibility in our code. As Douglas Adams famously said, 'A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools.'

As one final point, did you observe how in both the `WaitForSwitch()` and `RollTheDice()` functions we first presented the new value on the display (Lines 82 and 96) *before* generating the corresponding sounds (Lines 83 and 97)? In reality, everything is happening so fast here that we could easily have done things the other way, so, why am I even waffling on about this?

Suffice it to say that I started to think about how things happen when you are watching a cricket match and you see the batter hit the ball, followed a short time later by the sound of the bat meeting the ball. This is, of course, because light travels much faster than sound. Our brains are so accustomed to this discrepancy between the arrival times of visual and audible signals that we don't even think about it. In fact, if you asked most people, they would claim that everything happened at the same time.

I think it's safe to say that the fact I spent any amount of time cogitating and ruminating over this provides a classic example of how I often overthink things ('Obsessive compulsive – moi?').

Let's do it!

Are you as excited as your humble narrator? I bet you're not! Let's load our program into our Arduino Uno and run it.

It works! Did you ever doubt me? I don't know about you, but I think this actually looks pretty spiffy. So spiffy, in fact, that I just took a video of it running on my Arduino-breadboard combo and uploaded it to YouTube: **https://bit.ly/3PgTg0S**

One thing you'll spot in this video is that I've replaced my two momentary pushbutton switches with limit switches on flying leads. I did this because I wanted to get as much switch bounce as possible to ensure that our programs deal with it appropriately.

We want more!

OK, how about we jazz things up a little by generating a series of random numbers before settling on the final value?

As a starting point, let's say we wish to generate 16 random numbers over a period of 6 seconds, which means there will be a delay of 6/16 = 0.375s (375ms) between values. Since we know that the same number can come up multiple times, let's try blanking the display for say 100ms between values to visually delineate identical adjacent values (at some stage we will need to subtract this 100ms delay from our 375ms delay).

I think implementing this modification is going to be a lot simpler than you might suppose. Let's start by adding three new definitions: `NUM_ROLLS` (the number of random values we wish to generate), which we'll set to 16; `TIME_PER_ROLL` (the total time taken between values), which we'll set to 375ms; and `TIME_BLANK` (the blank period between values), which we'll set to 100ms.

Now, all that remains is for us to modify our `RollTheDice()` function to generate a series of 15 random values before finally settling on the 16th value, as illustrated in Listing 7.

Basically, all we've really done is to wrap the contents of our original function in a `for()` loop (we introduced this type of loop construct in *PE*, February 2023). Inside this loop, we first blank the display and wait for our `TIME_BLANK` delay. Next, we generate and display our new random value, generate our sound effect, and pause for a time calculated by subtracting the time taken

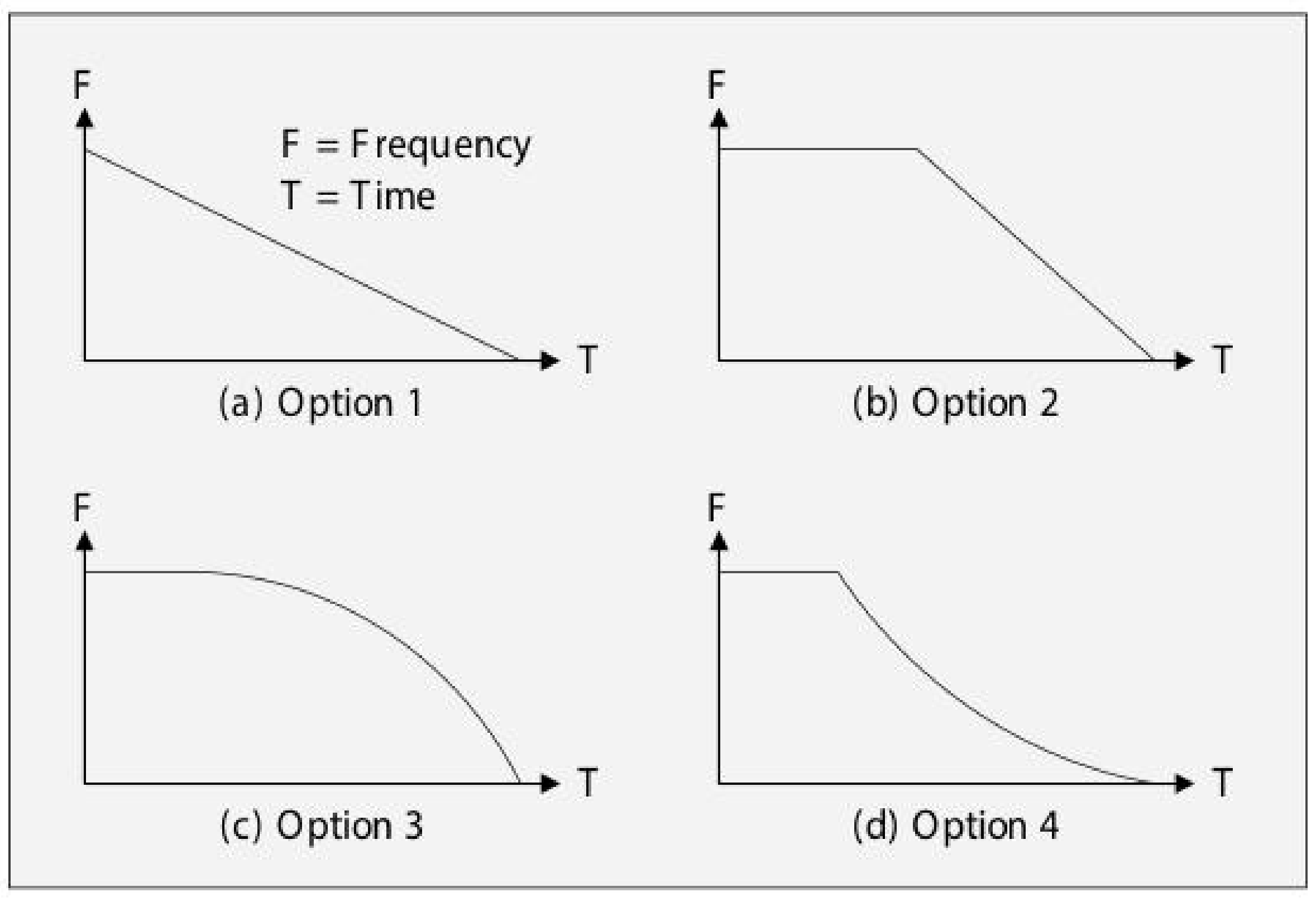


Fig.3. Initial envelope possibilities.

to blank the display from the total time we budgeted for each roll of the dice.

Once we exit the loop, we pause for our old `PAUSE_AFTER_ROLL` delay, which gives the user time to observe and (if necessary) jot down the final value before we return control to the main loop and do it all again. You can, of course, access this new version of our program (file **CB-Aug23-03.txt**). Also, for your delectation and delight, I just videoed this new version and uploaded it to YouTube, see: **https://bit.ly/3NzpO4X**

One-armed bandits

How could we add even more pizazz? Well, what about making our random numbers change quickly at first, and then have them start to gradually slow down before eventually settling on a final value? I'm thinking of the way classic one-armed bandit machines used to work; that is, slot machines with three electromechanical wheels operated by pulling a long handle (the arm) on one side. The act of pulling the handle set the wheels spinning and clicking to provide a strangely satisfying audio-visual experience. The wheels gradually slowed, stopping one after the other, building the user's anticipation.

I must admit that I'd never really thought about the thinking that went into this… until now. In our case, we have only one display (although just visualising one-armed bandits is making me contemplate adding two more). In physics and engineering, the term 'envelope' in the context of an oscillating signal refers to a curve or line outlining its extremes. Right from the get-go, I can visualise four obvious contenders on the envelope front (Fig.3)

The simplest alternative would be to just slow the display in a linear fashion (Fig.3a). A slightly more sophisticated option would be to have the display change at a constant speed for some amount of time, after which it could commence its linear descent (Fig.3b). We could, of course, be tempted to tart things up a tad by replacing the straight-line decline, as seen in Fig.3b, with a curvaceous counterpart, as shown in Fig.3c. Alternatively, we might contemplate replacing the convex curve from Fig.3c with its concave cousin in Fig.3d.

Over thinking and over engineering

It's one thing to sketch out the conceptual curves illustrated in Fig.3. However, coming up with actual values is another kettle of fish, as they say. Why don't you take a moment to ponder how you would set about doing this yourself.

You really didn't spend much time pondering, did you? I never even saw your eyes blink between the previous paragraph and this one.

Just for giggles and grins, let's start by showing you the envelope I ended up using (Fig.4), and then I'll describe the tortuous path that got me there. As you can see, this isn't as smooth as one might hope. There are a couple of discontinuities (especially the point around 1.75 seconds), but I didn't realise that until I just drew this figure and I'm not going to change things now!

The really interesting point is that this is somewhat more subtle than I would have supposed. We kick off at time 0 with a straight line to around 1.5 seconds, then we have a concave curve to around 3.5 seconds, at which point we transition into a convex curve until our last value, which occurs at a tad over six seconds.

I was chatting to my chum Joe Farr about this a few days ago (after I'd generated the data that ultimately led me to the envelope shown in Fig.4). I explained what I was trying to do with respect to modifying the rate with which the values change, and then I asked Joe how he would have done this. He replied that he would have simply 'guestimated' a bunch of values and gone from there.

Do you recall me saying that I often overthink things? Well, oftentimes I also overengineer them as well (sometimes I even amaze myself with the convoluted hoops I end up making myself jump through). In this case, I have an application called Camtasia – see: **https://bit.ly/3PfbX5h** – which I usually use to record videos of myself embedded in PowerPoint presentations as part of creating webinars. In this case, I recorded myself clapping my hands trying to replicate the sort of transition rate I was hoping to see (Fig.5).

If you are interested, you can listen to the audio recording of this (file **CB-Aug23-04.m4a**). I then used the cursor in Camtasia to read off the time values for the individual claps, which I stored in an Excel spreadsheet (file **CB-Aug23-05.xlsx**).

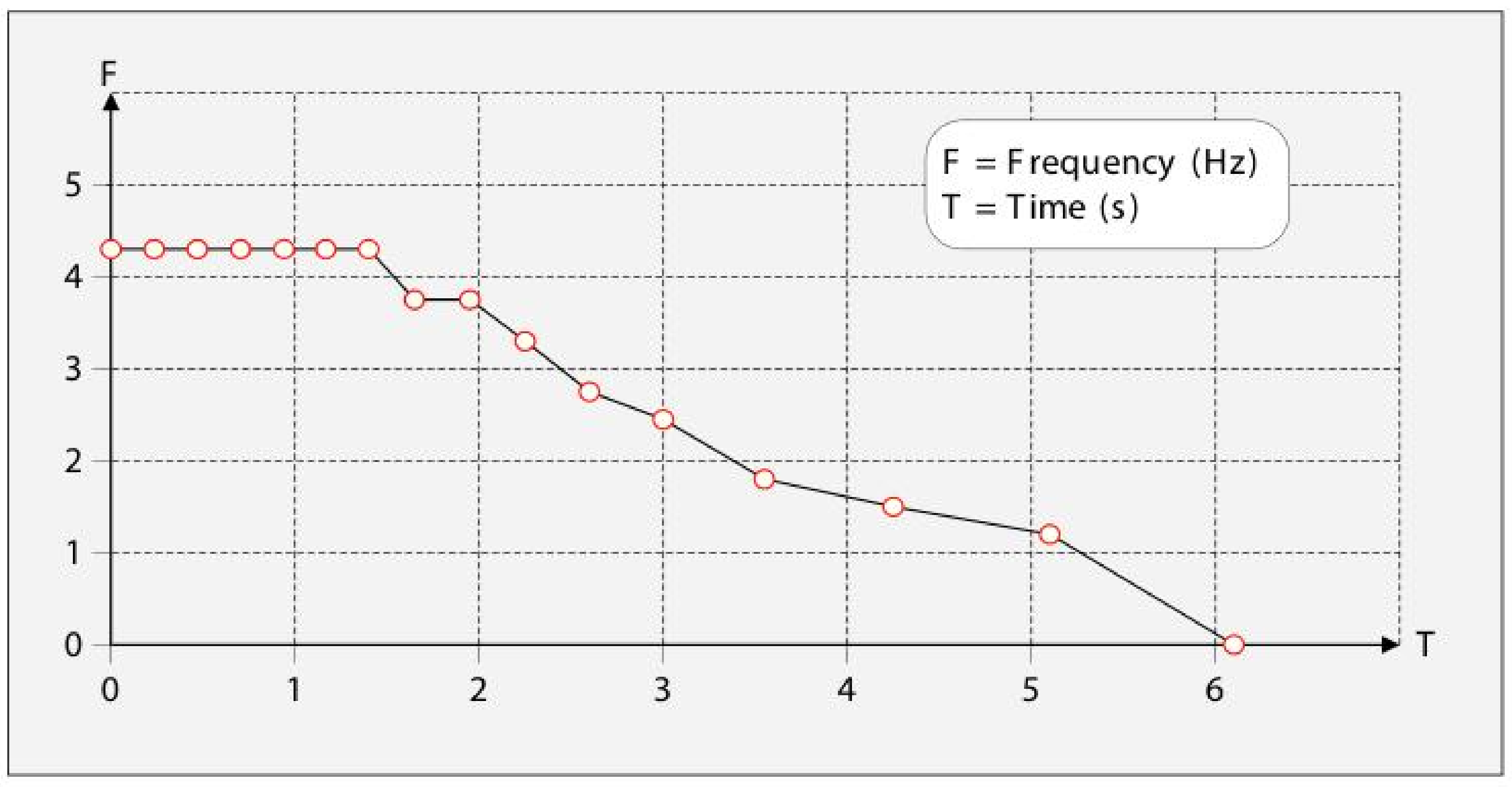
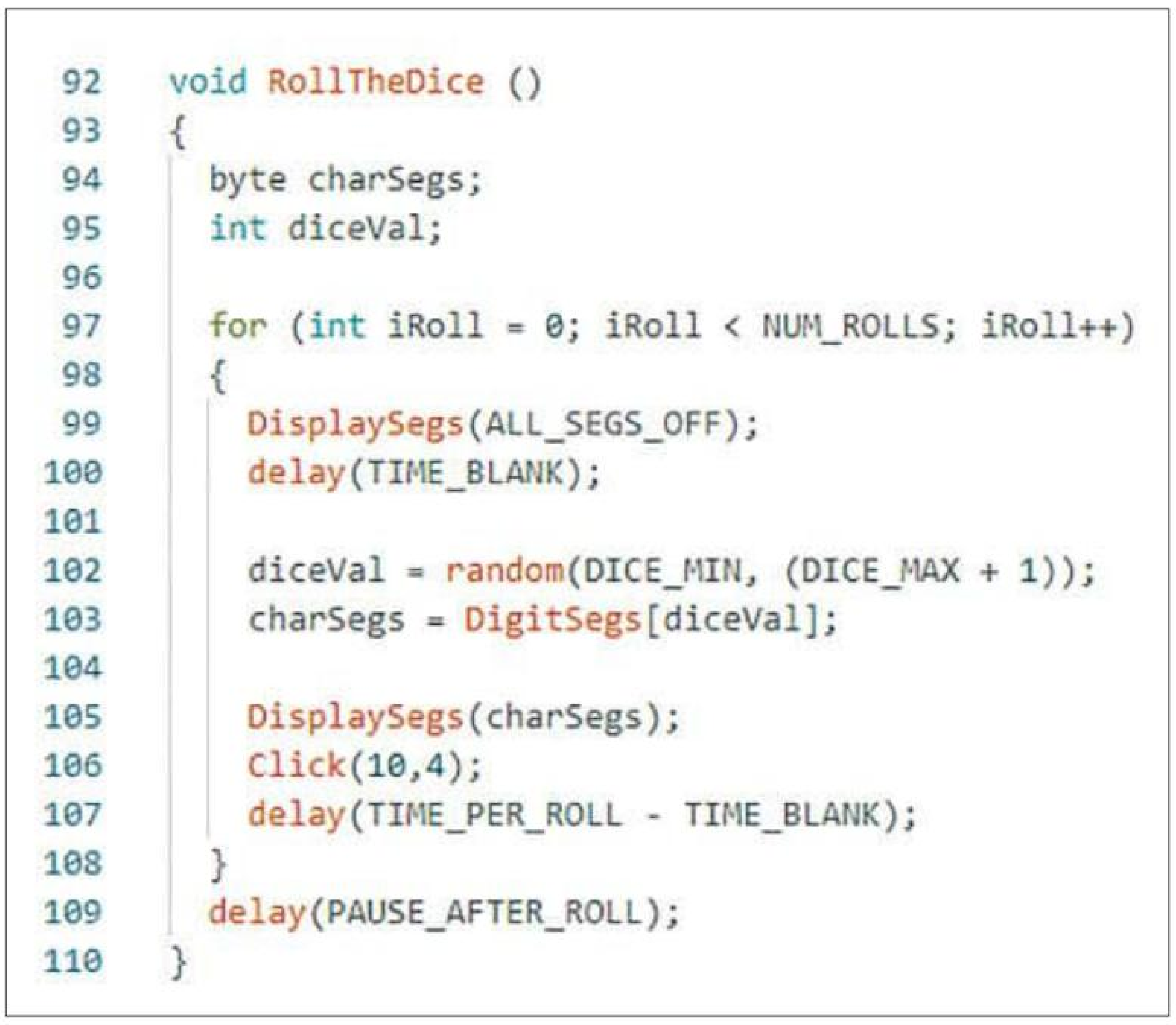


Fig.4. The actual envelope used.



```
void RollTheDice ()
{
  byte charSegs;
  int diceVal;

  for (int iRoll = 0; iRoll < NUM_ROLLS; iRoll++)
  {
    DisplaySegs(ALL_SEGS_OFF);
    delay(TIME_BLANK);

    diceVal = random(DICE_MIN, (DICE_MAX + 1));
    charSegs = DigitSegs[diceVal];

    DisplaySegs(charSegs);
    Click(10,4);
    delay(TIME_PER_ROLL - TIME_BLANK);
  }
  delay(PAUSE_AFTER_ROLL);
}
```

Listing 7. Generating a series of random values.

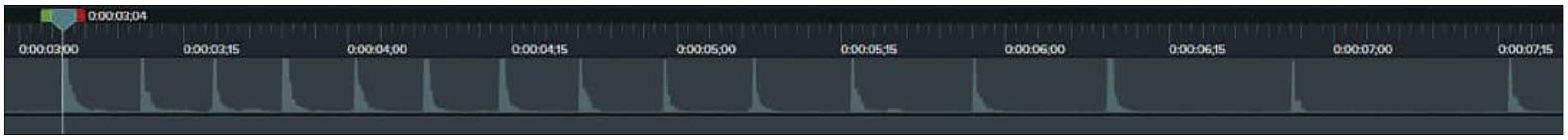


Fig.5. Screenshot of Camtasia recording of clapping my hands.

Click Nums	Delta Times	Renormalised Times	Freq (Hz)
#01	0.000	0.000	4.29
#02	0.233	0.233	4.29
#03	0.233	0.466	4.29
#04	0.233	0.699	4.29
#05	0.233	0.932	4.29
#06	0.233	1.165	4.29
#07	0.233	1.398	4.29
#08	0.266	1.664	3.76
#09	0.266	1.930	3.76
#10	0.300	2.230	3.33
#11	0.367	2.597	2.72
#12	0.407	3.004	2.46
#13	0.560	3.564	1.79
#14	0.667	4.231	1.50
#15	0.827	5.058	1.21
#16	N/A	6.058	0.00

Fig.6. Summary of spreadsheet values.

My clapping commenced 3.133s into the recording (prior to this I was performing my limbering-up exercises to prepare myself for the ordeal). The first time round, I ran into a bit of a snag since the cursor 'auto-clicks' from 0:00:03;00 to 0:00:03;01 to 0:00:03;02 etc. The first three colon-separated numbers represent hours, minutes, and seconds. I initially assumed that the 01, 02, 03 values following the semicolons were hundredths of a second. However, when I entered these values into my spread sheet, I observed big discontinuities at the transitions from one second to another.

When I looked more closely, I realised that Camtasia counts from 0:00:03;00 to 0:00:03;29, from whence it transitions to 0:00:04;00. That is, each second is divided into 30 parts. This means that, for my purposes, a value of 0:00:03;15, for example, equates to 3s plus (1/30 * 15) seconds, which equals 3.5s in all.

If you do happen to look at the spreadsheet (a summary is provided in Fig.6), you'll see that I first normalised things by subtracting the 3.133 starting time from all the values. Next, I calculated the deltas between values, tweaked these deltas, and generated renormalised values from the tweaked deltas (these are the horizontal time (X) values used to generate Fig.4).

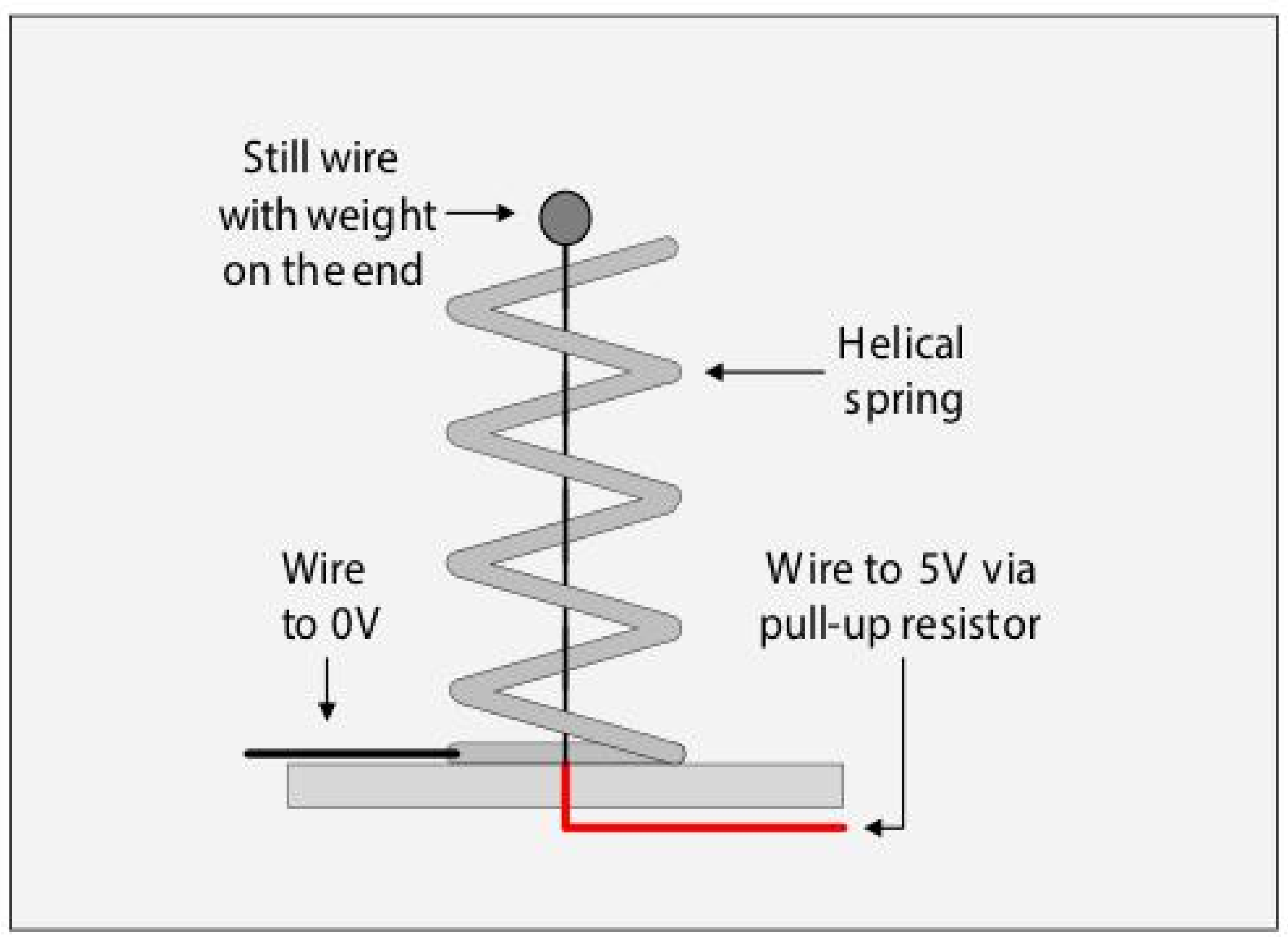

Still wire with weight on the end
Helical spring
Wire to 0V
Wire to 5V via pull-up resistor

Fig.7. DIY trembler switch.

I also used the tweaked deltas (which are measured in milliseconds) to generate the vertical frequency (Y) values used to generate Fig.4. As we previously noted, it was only after I actually drew Fig.4 that I realised there was some further tweaking that could be performed, but by then I'd already written my program and I decided enough was enough.

On the one hand, you might say that this was a lot of expended effort for relatively little result. I would disagree. If I had taken the easy route, I would never have known about the combination of concave and convex elements forming my envelope. Based on past experience, I would say that this knowledge will come in handy one day (almost everything I've ever learned has proved to be useful... eventually).

So, what's the result?

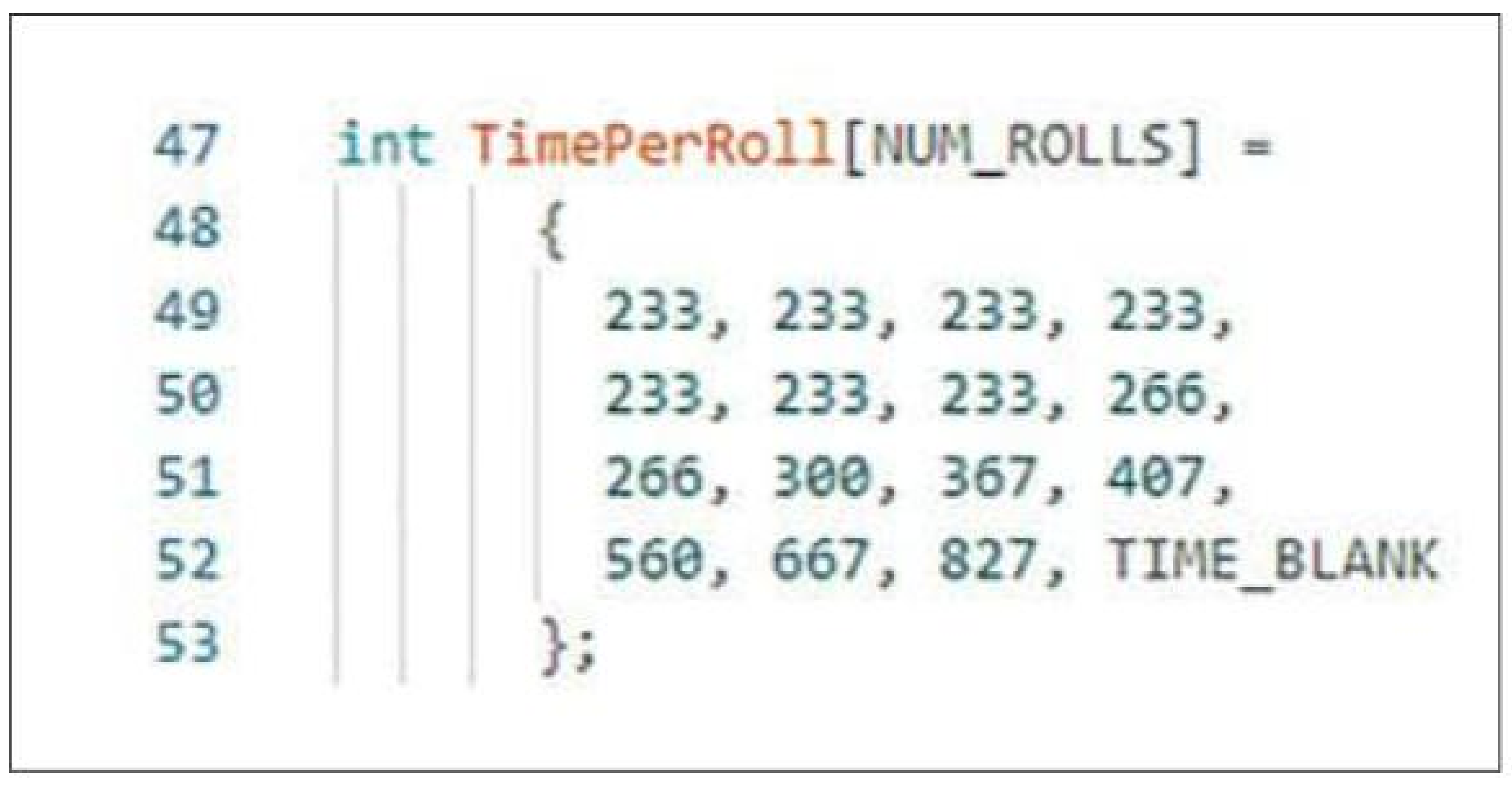
To benefit from our efforts above, we must modify our program. Once again, the way we've architected things means that this is going to be a lot easier than you might, at first, suppose.

To start things off, we will delete our `TIME_PER_ROLL` definition, because we now have individual times associated with each digit. As a replacement, we are going to add an array of integers called `TimePerRoll[]` containing our Delta Times from Fig.6, as illustrated in Listing 8.

The reason for setting the final value to `TIME_BLANK` will become apparent when we look at the latest and greatest version of our `RollTheDice()` function, as illustrated in Listing 9.

You know those quizzes where you are presented with two identical-seeming photos, and your task is to spot the differences between them? Well, can you spot the differences between the `RollTheDice()` functions in Listings 7 and 9?

Actually, saying 'differences' is a bit of a red herring because there's only one change. The `TIME_PER_ROLL` constant value in Line 107 in Listing 7 has been replaced with a variable value extracted from our `TimePerRoll[]` array in Line 114 of Listing 9.



```
int TimePerRoll[NUM_ROLLS] =
    {
      233, 233, 233, 233,
      233, 233, 233, 266,
      266, 300, 367, 407,
      560, 667, 827, TIME_BLANK
    };
```

Listing 8. Delta times for each roll.

This explains why we set the final value in our `TimePerRoll[]` array to be `TIME_BLANK`, because this will result in a delay of (`TIME_BLANK – TIME_BLANK`) = 0 following the final roll of the dice.

To be honest, I'm rather proud of the result. You can access the latest version of this program (file **CB-Aug23-06.txt**). And, once again, I just uploaded a video of this new implementation to YouTube at: **https://bit.ly/442TpcD**

Trembling in anticipation

Do you remember the classic Monty Python *Nudge Nudge Wink Wink* sketch (**https://bit.ly/3Xf3ot8**)? Did you ever play on an old pinball machine? Some rascally players used to lift, tilt, or shake the machine to gain advantage if the occasion allowed (a special tilt mechanism was used to detect if the machine was being lifted, tilted or shaken beyond an acceptable level).

The reason I ask these seemingly unconnected questions is that I was thinking that we might add a 'nudge nudge' feature to the most recent version of our program. In order to do this, we could build a DIY 'trembler switch', as illustrated in Fig.7.

The idea is to have a stiff helical spring mounted on some sort of base. This spring would be connected to 0V. Running up the center of the spring would be a stiffish wire with a small weight attached to the end (a big blob of solder would do). This wire would be connected to 5V via a pull-up resistor (anything from 1kΩ to 10kΩ would work.

Components from Part 1

LEDs (assorted colours)	**https://amzn.to/3E7VAQE**
Resistors (assorted values)	**https://amzn.to/3O4RvBt**
Solderless breadboard	**https://amzn.to/3O2L3e8**
Multicore jumper wires (male-male)	**https://amzn.to/3O4hnxk**

Components from Part 2

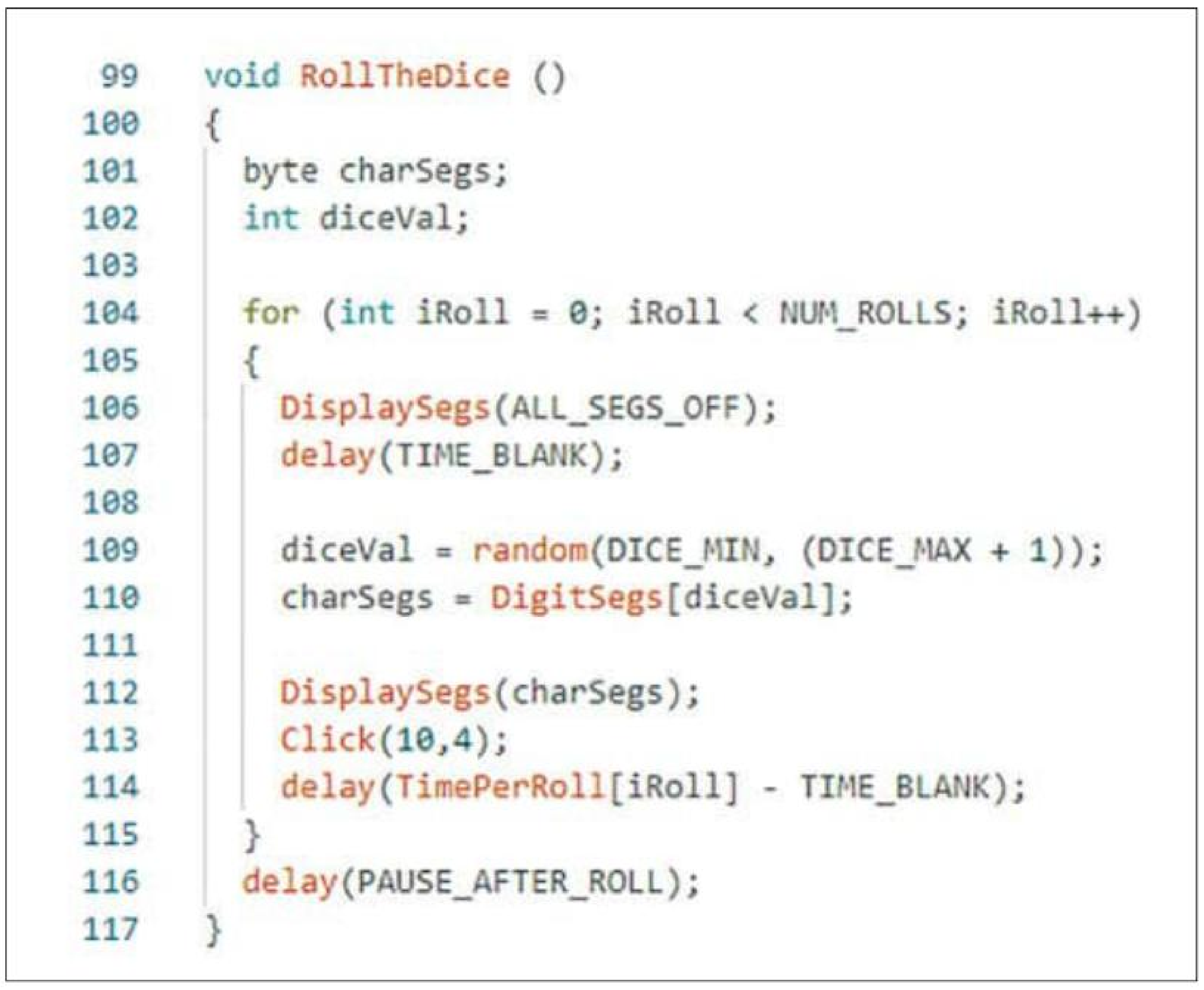
7-segment display(s)	**https://amzn.to/3Afm8yu**

Components from Part 5

Momentary pushbutton switches	**https://amzn.to/3Tk7Q87**

Components from Part 6

Passive piezoelectric buzzer	**https://amzn.to/3KmxjcX**



```
void RollTheDice ()
{
  byte charSegs;
  int diceVal;

  for (int iRoll = 0; iRoll < NUM_ROLLS; iRoll++)
  {
    DisplaySegs(ALL_SEGS_OFF);
    delay(TIME_BLANK);

    diceVal = random(DICE_MIN, (DICE_MAX + 1));
    charSegs = DigitSegs[diceVal];

    DisplaySegs(charSegs);
    Click(10,4);
    delay(TimePerRoll[iRoll] - TIME_BLANK);
  }
  delay(PAUSE_AFTER_ROLL);
}
```

Listing 9. Roll the dice with changing times.

If you think about it, this would be like adding a third switch to our existing pushbutton switches in Fig.1. In this case, we could take the center tap point and feed it to the Arduino's A2 analogue pin. Banging the table on which this switch resides would cause the center wire to oscillate. A sufficient shock will cause the wire to touch the spring, thereby closing the circuit.

The way we could make this work is, once our program is displaying its final value, if our trembler switch is triggered ('nudged') anytime during the `PAUSE_AFTER_ROLL` delay, then we could perform one more random roll (this time we *would* add a check to make sure this new random number is not the same as our previous random value).

How about we all go off and create our own implementation of this? We'll meet up again next month and see how well we did and how your solution compares to mine. Until next time, have a good one!

Online resources

For the purposes of this series, I'm going to assume that you are already familiar with fundamental concepts like voltage, current and resistance. If not, you might want to start by perusing and pondering a short series of articles I penned on these very topics – see: **https://bit.ly/3EguiJh**

Similarly, I'll assume you are no stranger to solderless breadboards. Having said this, even if you've used these little scamps before, there are some aspects to them that can trap the unwary, so may I suggest you feast your orbs on a column I wrote just for you – see: **https://bit.ly/3NZ70uF**

Last, but not least, you will find a treasure trove of resources at the **Arduino.cc** website, including example programs and reference documentation.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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AUDIO OUT

By Jake Rothman

Demolition Derby

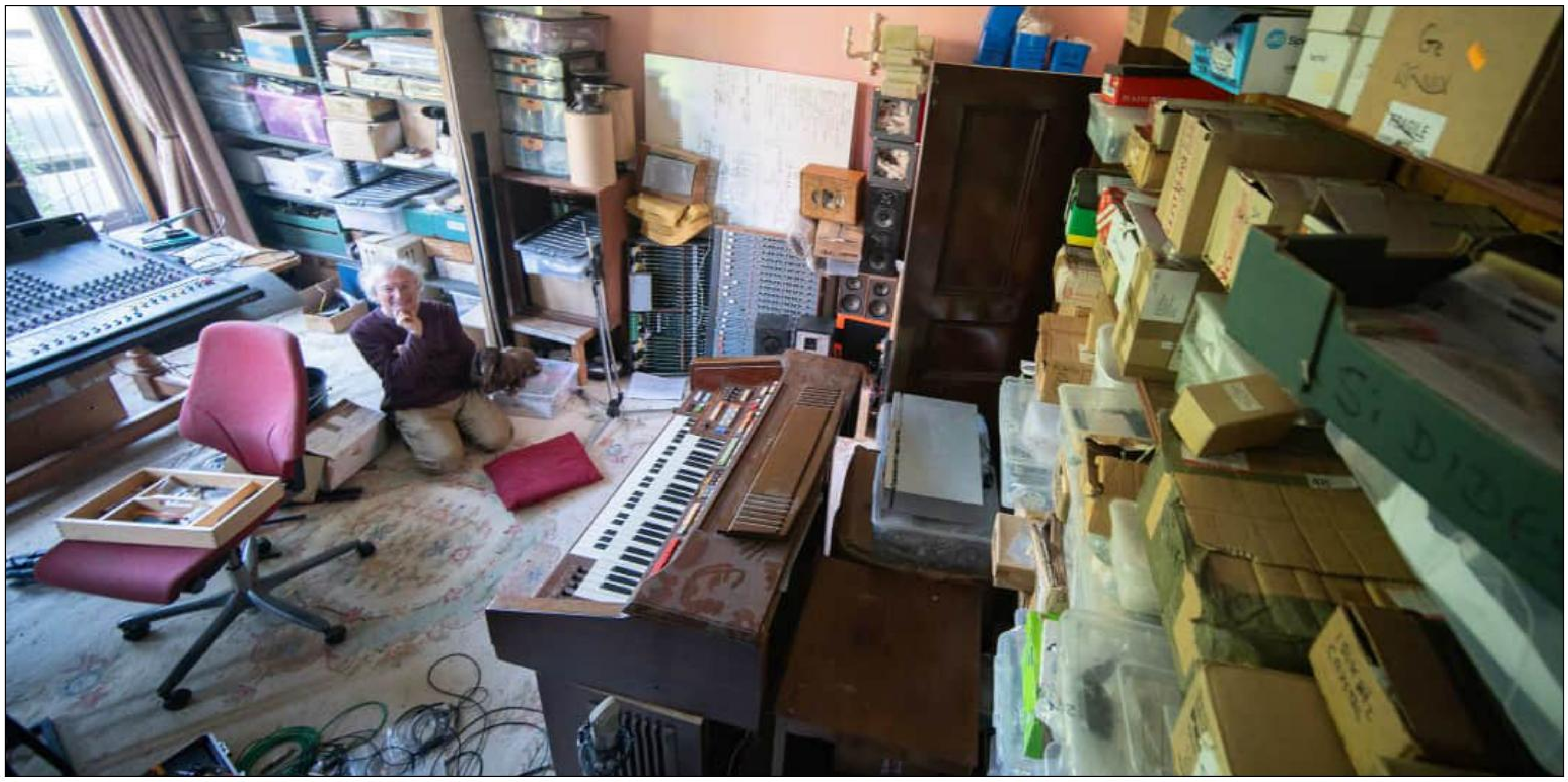


Fig.1. Every workshop needs a storeroom, but this is out of control. (Photo: Harvey Rothman)

Every so often my workshop storeroom, shown in Fig.1, has to be cleared. This is true now, more than ever, since the time for 'downsizing' has finally arrived – the kids have left home, the price of gas is insane and I'm moving from a huge Victorian money pit (mansion) to something much more sensible (and affordable). In the new place, large pieces of equipment will have to justify their retention, rather than just being a project I might get around to one day. This meant I had to have an unsentimental look at several decades' worth of collecting/hoarding/scavenging and get rid of a lot of equipment – the question was, how? The following, slightly unusual article describes several approaches, which many readers may find useful when they realise their own collection of electronic ephemera and white elephants has got out of hand and some/all of it needs to go. I used a combination of selling, cannibalising parts, demolition and recycling.

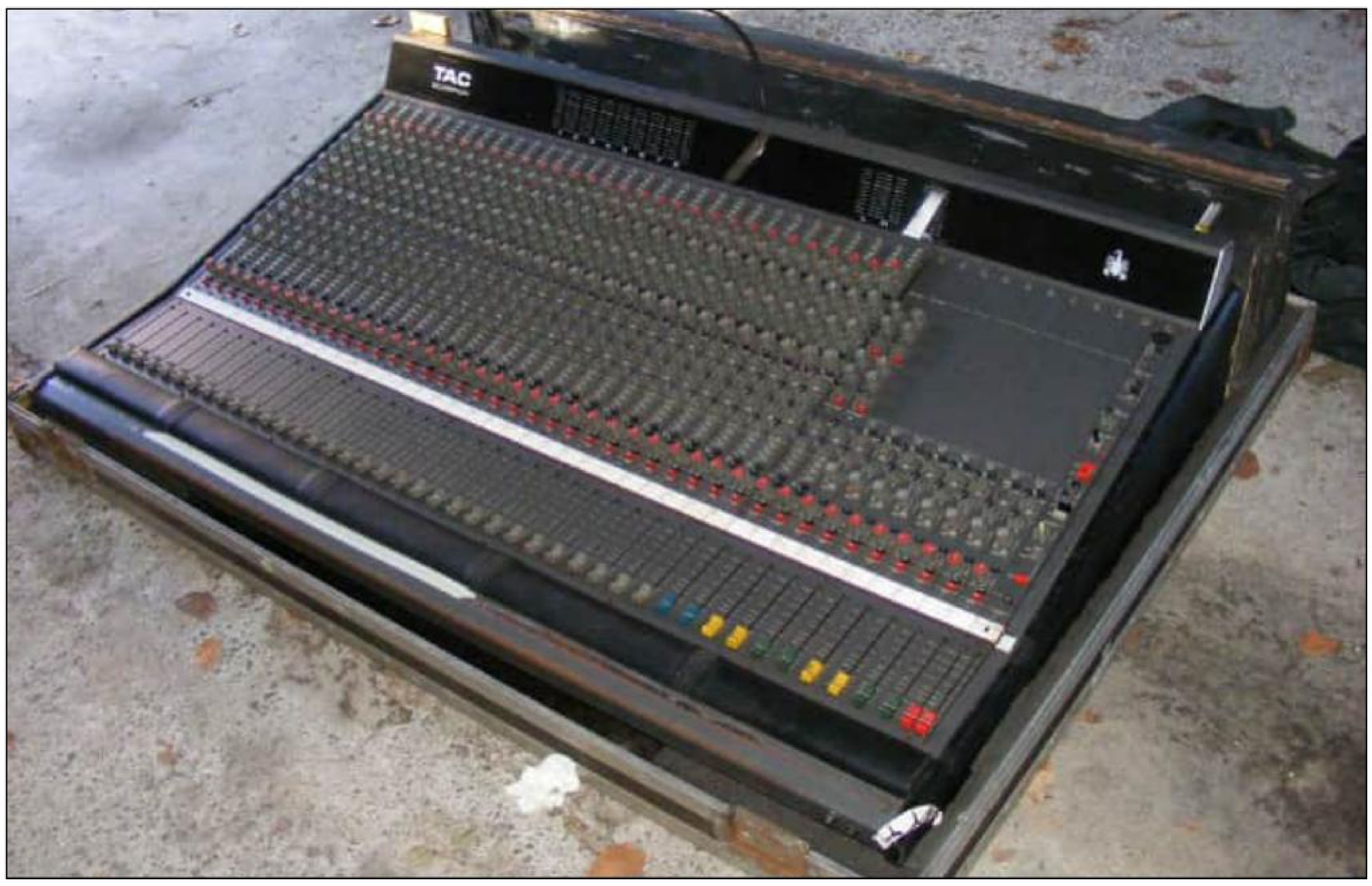


Fig.2. The huge TAC Scorpion mixing desk – does it deserve to live on?

Surveying the storeroom, it was clear that the main space hogs were four mixing desks, including a couple of TAC Scorpions. These had recently been donated by the local music festival company, which had carelessly stored them in a leaking barn. The 60+kg, two-metre wide behemoths, shown in Fig.2 cost over £5000 in 1989, but are now worthless. I noticed one sold on eBay for £183 – but it was made clear that it was collection only (no surprise!).

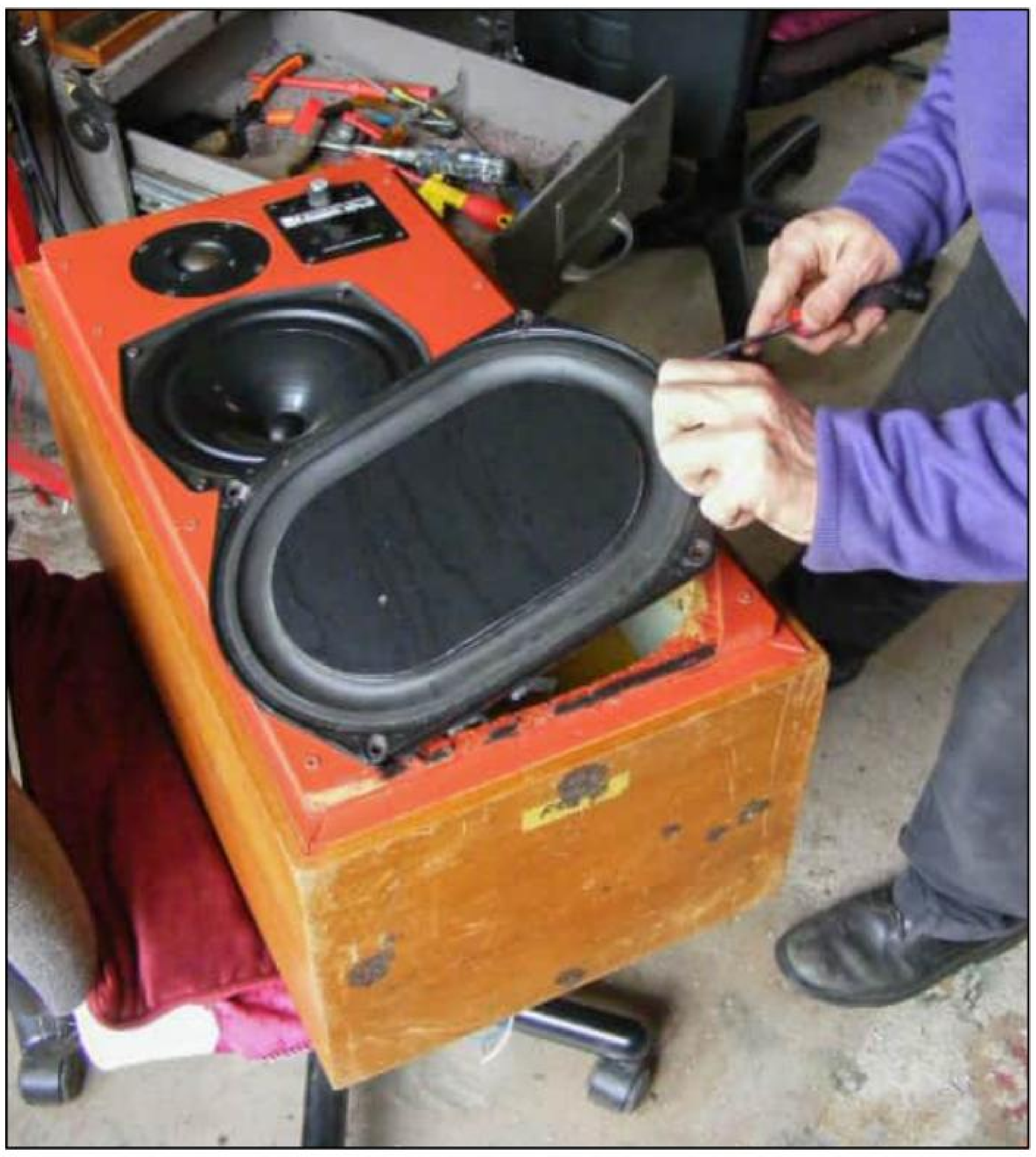


Fig.3. Sadly, these old KEF speakers were broken up and I sold the driver units and crossovers as spare parts.

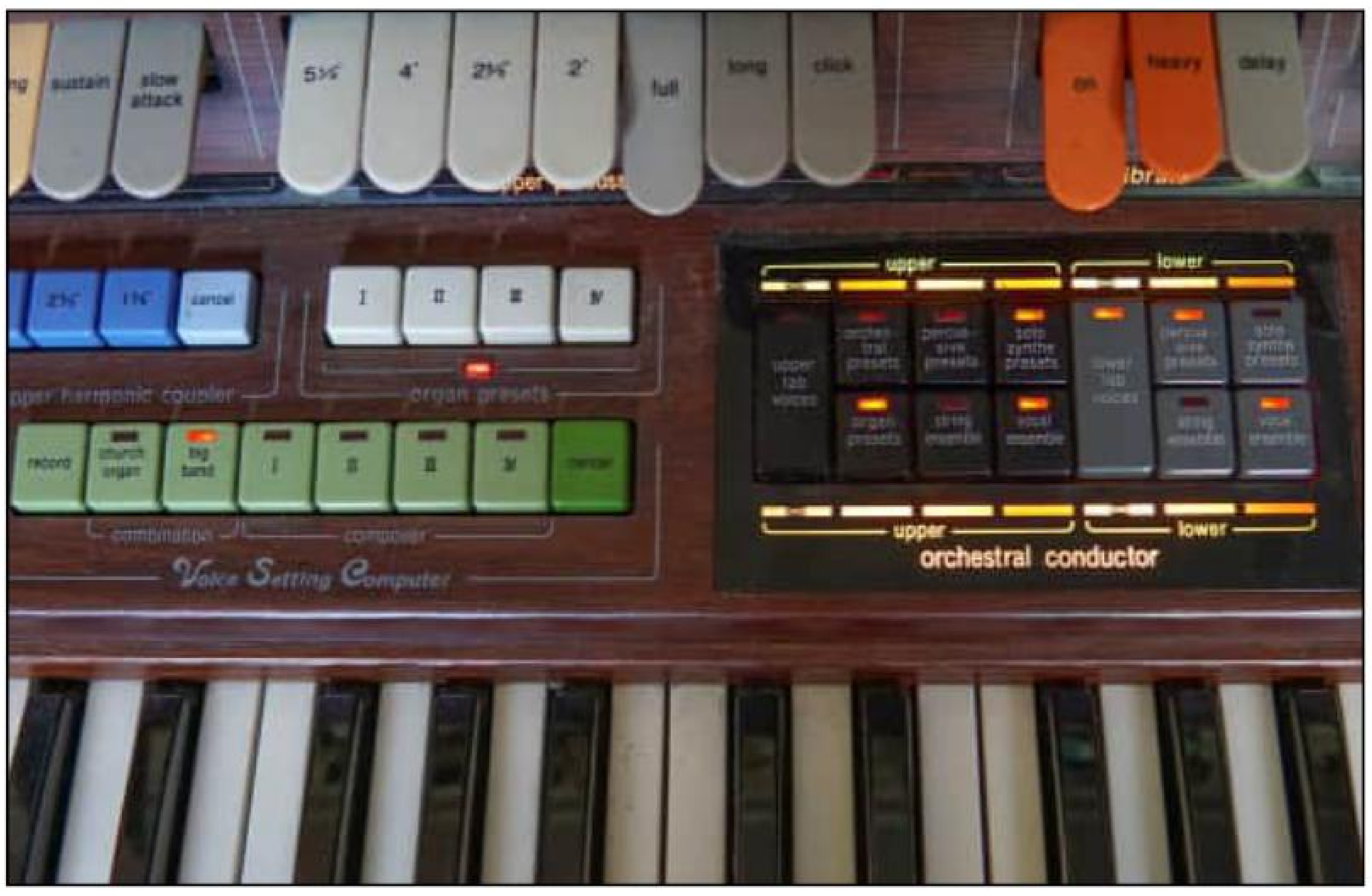


Fig.4. This organ is too big, but on the plus side the illuminated latching push buttons feel like I'm using a 1960s Star Trek console.

Loudspeakers

Speakers were another major space sucker. I had a graveyard of 40 pairs of assorted models – what a waste of a Victorian drawing room! The collection dated back to the early 1990s when I was designing crossover networks for Mordaunt-Short. A strange thing about speakers is that the sum of their parts is often valueless, but the bare drivers sell for reasonably high prices. This is especially true for KEF speakers. Their chipboard flat cabinets are considered ugly, while their Bextrene bass units and T27 tweeters are highly valued. This kind of cannibalisation had to be done to the KEF 104aB speakers shown in Fig.3. It was worth (possibly) £40 intact, but it generated £150 from easily postable drive units.

A huge flagship Technics SX-U90 electronic organ (see Fig.4) also resides in the workshop. Despite almost working and having a beautiful control surface lit with soft filament lamps, it has negative value. I'm offering it free to a collector, because it's eating up valuable real estate. What's the solution if nobody turns up? Strip out the spring-line reverb, bucket brigade chorus delay chips and speaker drivers and dump the rest. It's a shame, since there is probably an enthusiast who's missing a few of its unique push buttons.

Recycling

Recycling can be effective, but it only works if materials are strictly separated. Another big problem with recycling electronics is that the only items that can be profitably recycled are the metals. I collected all the steel and copper cabling separately and sold what I could. Old PCBs and connectors have to be removed because leaded solder can cause contamination when incinerated. (Reselling working components, however, can be more lucrative.)

Unfortunately, the downside of recycling is that it encourages rampant consumerism – it really is much better to reuse or repair whenever possible.

What to do?

Having found solutions for the organ and speakers, it was now the turn of the Scorpion mixers. I had two similar units – but one had to be scrapped (thanks to my local Welsh damp weather). These desks were designed to be easily maintained – fully modular with solid metalwork. I naively thought one could be repaired, played with, and then sold on, but it didn't work.

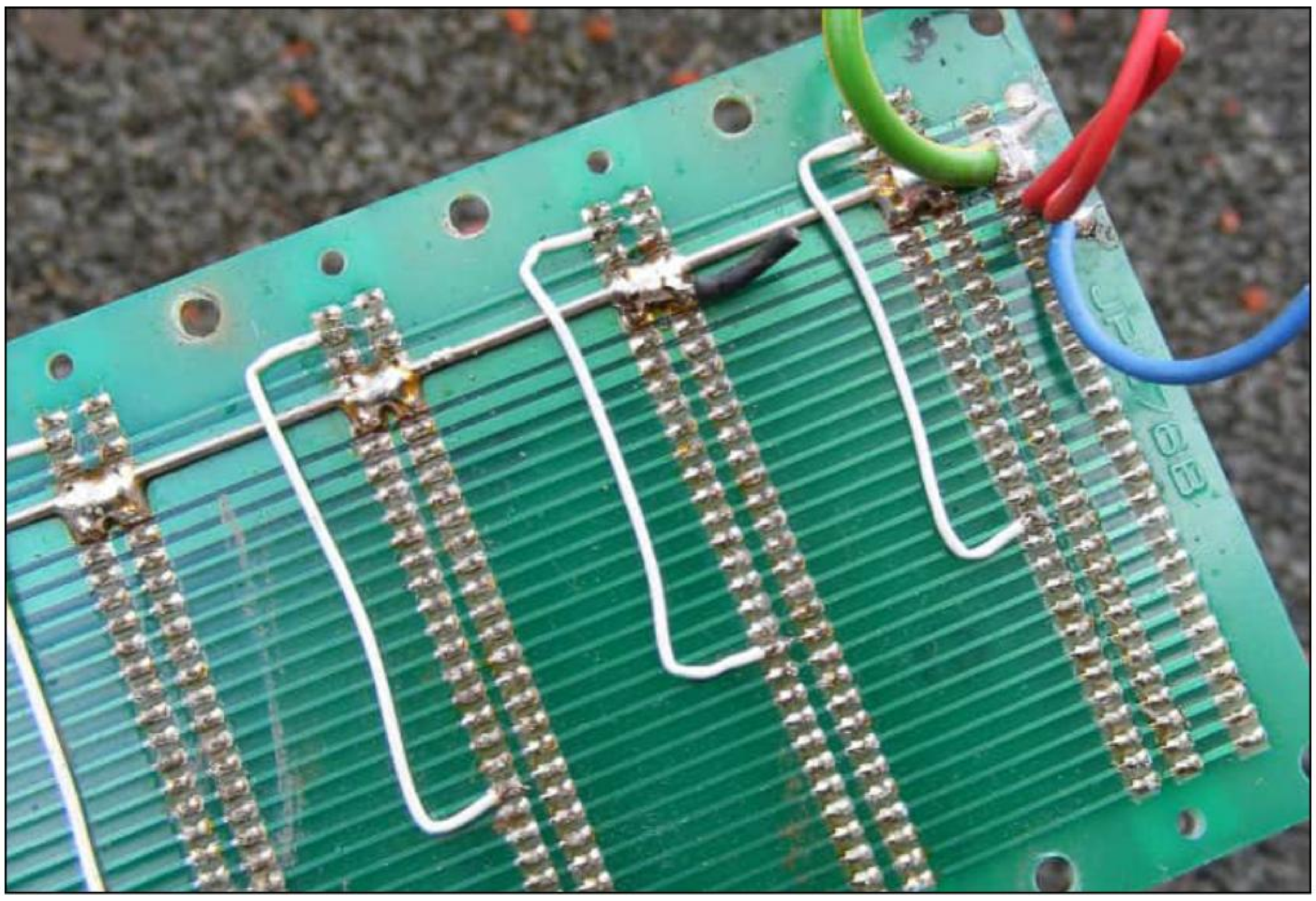


Fig.5. Demolition can reveal useful construction techniques. Notice the thick conductor soldered on the earth pins of the mixer's bus board.

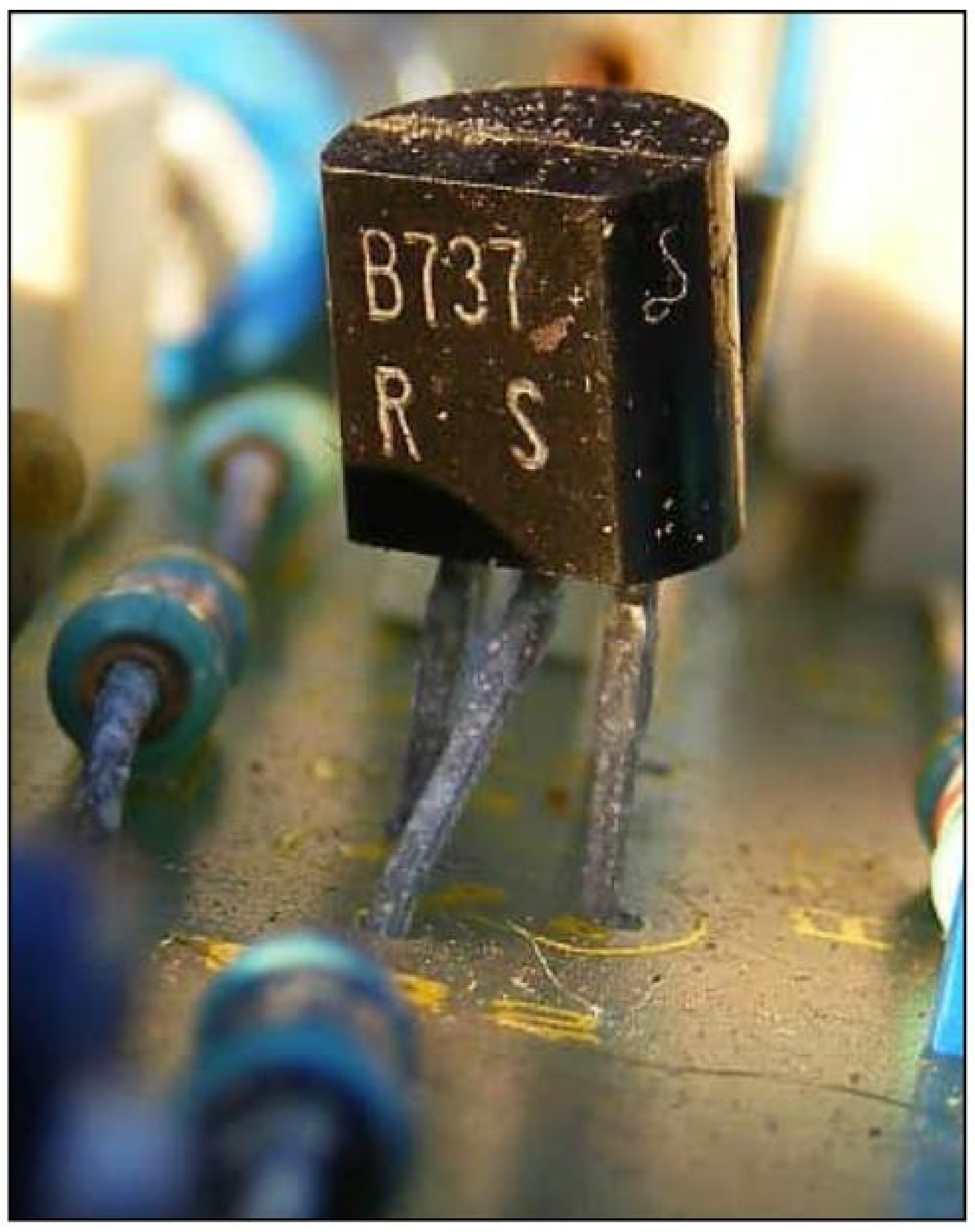


Fig.6. This old DDA mixer has the elusive 2SB737 input transistors. Vinyl aficionados pay big money for these. Nothing works better with moving-coil cartridges.

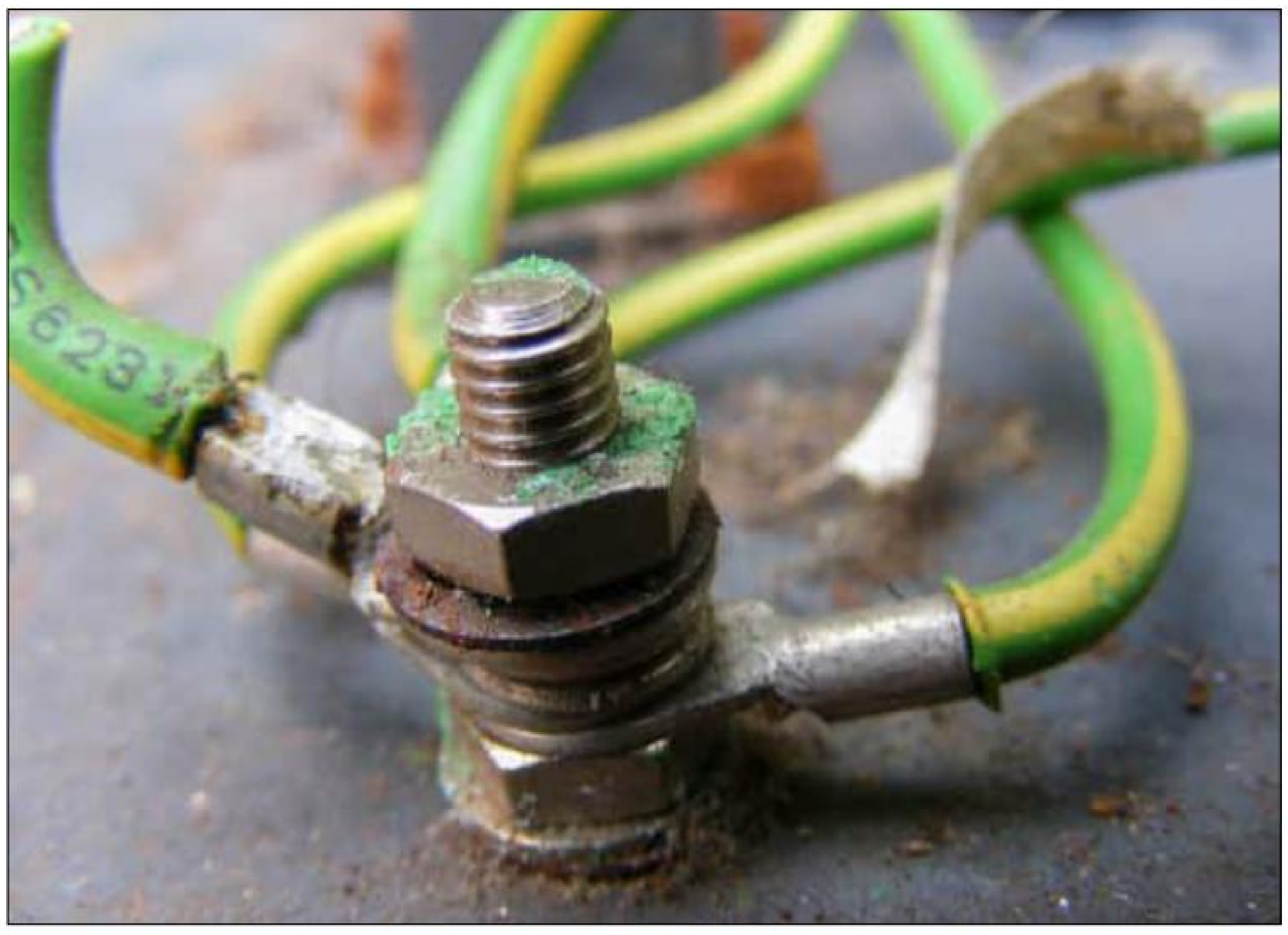


Fig.7. The hidden cause of all the trouble that resulted in the desk being discarded: the main earthing post on the chassis was oxidised and not tightened up properly.

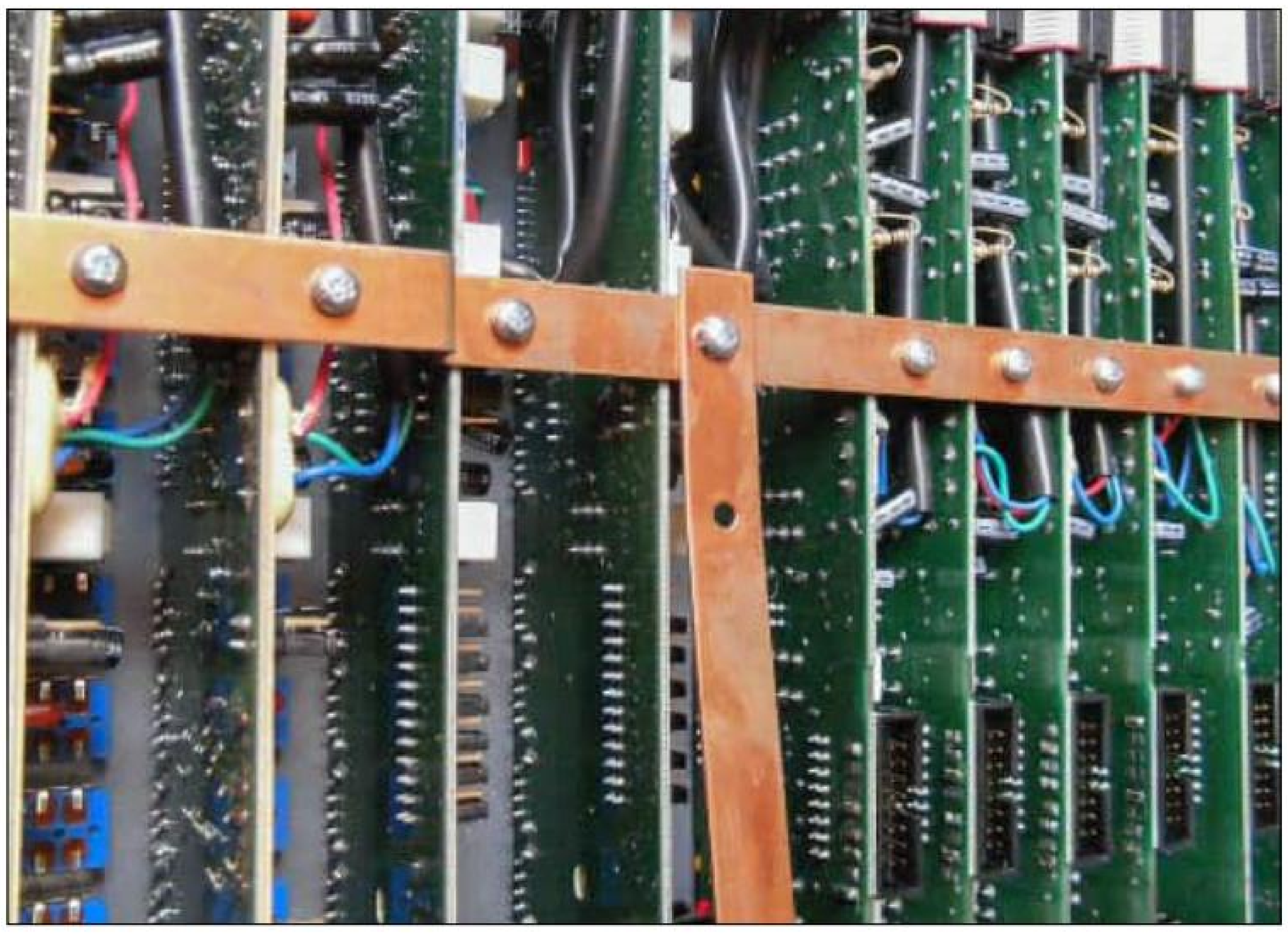


Fig.8. Another earthing disaster – this chunky copper earth bus on an Allen and Heath mixer was effectively disconnected due to rusty screws. I upgraded to stainless steel screws / shake-proof washers.

Hidden gems

Careful disassembly during scrapping can reveal useful in-house manufacturing techniques, such as the earthing in Fig.5. There can also be 'hidden gems' like the 2SB737 transistors (Fig.6) used in the input stages of the DDA (Dave Dearden Associates) and Allen and Heath mixing desks. These low-noise transistors are unique and no longer made. They are the best device for low source impedance applications, such as moving-coil pickup and ribbon microphone pre-amps thanks to their base spreading resistance of less than 2Ω. They were wasted in these mixers, so I took them out. A good 'swap' is the 2SA970, which matches well with standard microphones.

Faults revealed

Finding the fault that killed a piece of equipment after you've demolished it is more common than is admitted. The scrapped Scorpion mixer had terrible random bangs/hums. It turned out the well-hidden main ground stud (Fig.7) was loose and corroded.

The Allen and Heath mixer had corroded mild steel screws on its copper main earthing busbar. Replacing these screws with new ones made it work perfectly, as shown in Fig.8. It's smaller, so more saleable, and it's no use to me because I can't get my fat fingers between the knobs.

IDCs, or 'insidious death connectors' (more correctly known as insulation displacement connectors) work by pressing a spike into a ribbon cable, as shown in Fig.9. They are a great idea in sunny California, but a disaster in damp climates unless you use the sealing jelly that phone companies use. Sometimes the ribbons even just get torn off, as shown in Fig.10. These, along with corroded jack socket switch contacts on the insert points (Fig.11) cause the most common signal loss faults on analogue mixers.

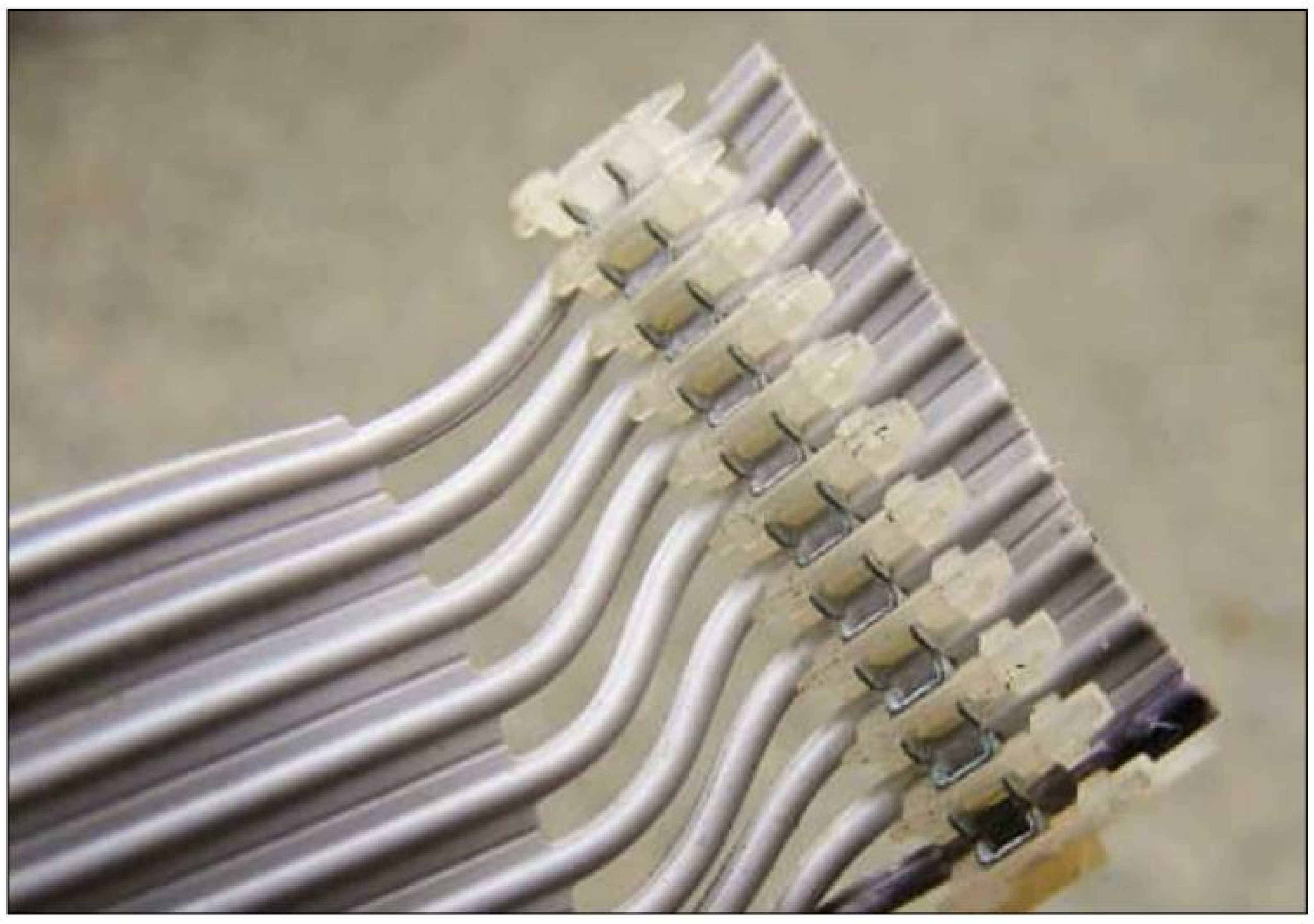


Fig.9. Oxidised ribbon IDC connector. Most mixers are full of these. They connect all the modules to the sockets on the back and are the most unreliable component in the system.

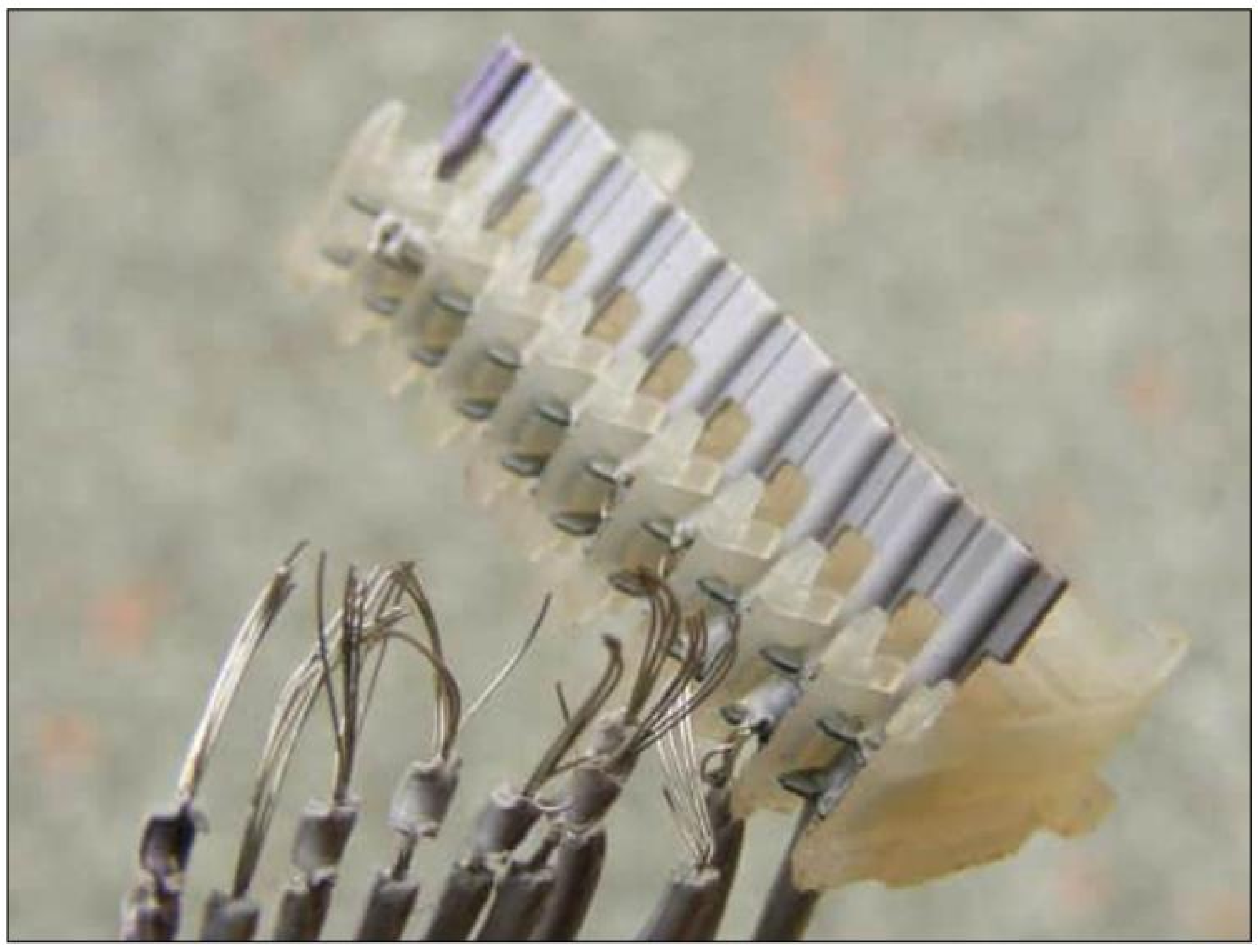


Fig.10. IDC ribbon connectors cannot withstand any force. The cable is often ripped off during servicing.

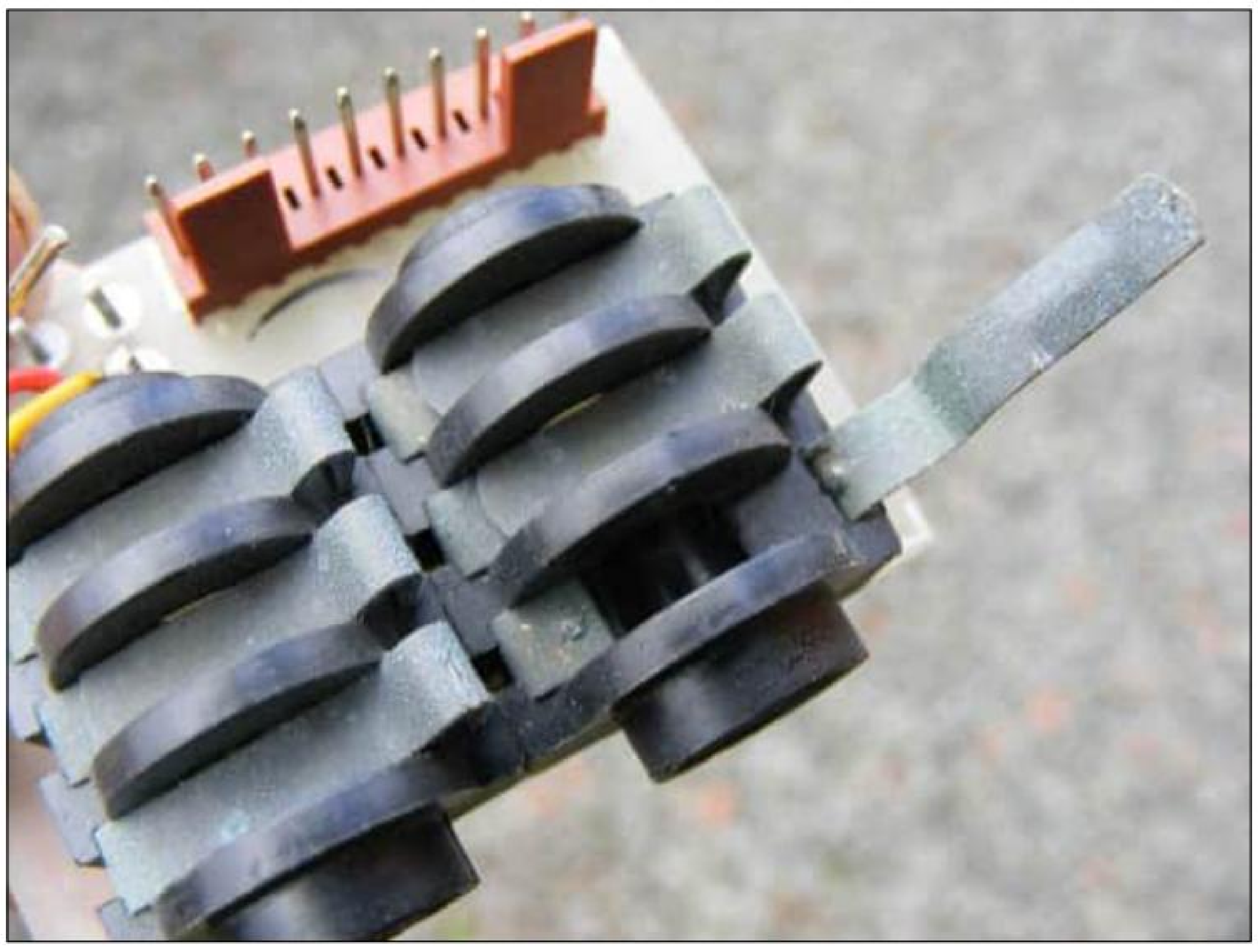


Fig.11. Jack sockets frequently oxidise. If the switch contacts are employed for passing the signal through, as in insert points, it causes loss of a channel.

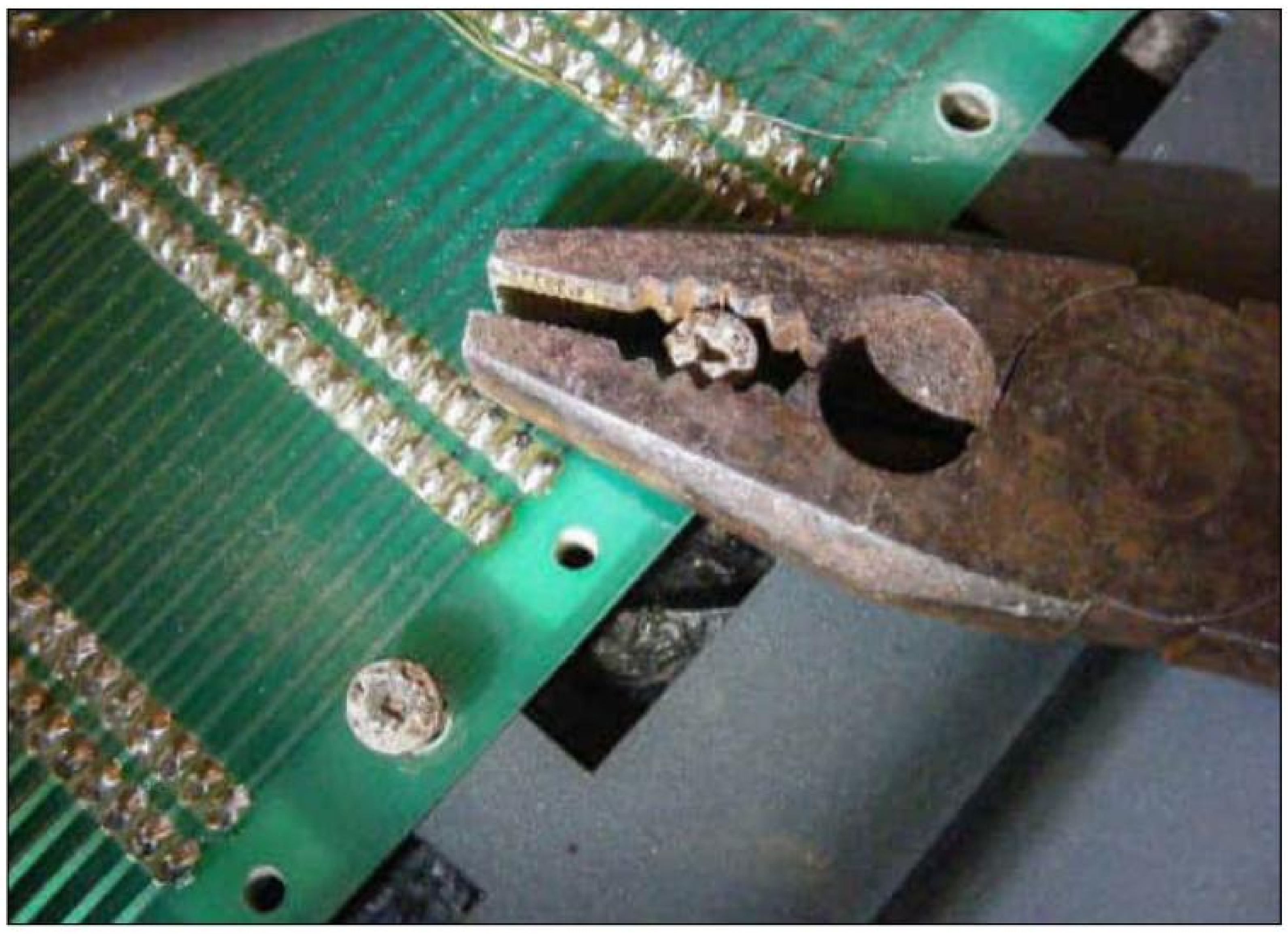
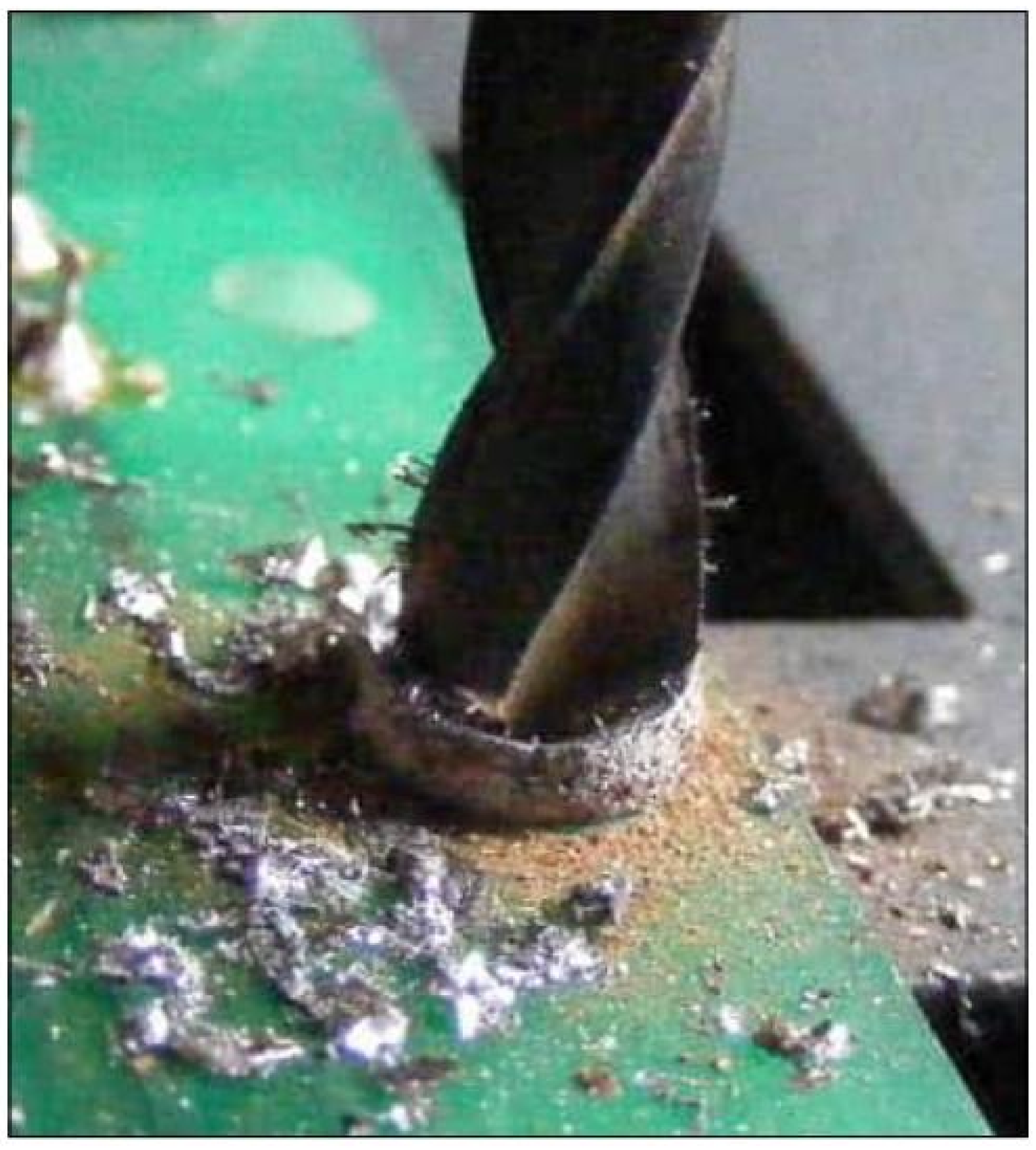


Fig.12. If you've chewed the screw head and can't undo it, then pliers can help, but only if you've got enough access room to wiggle them about.



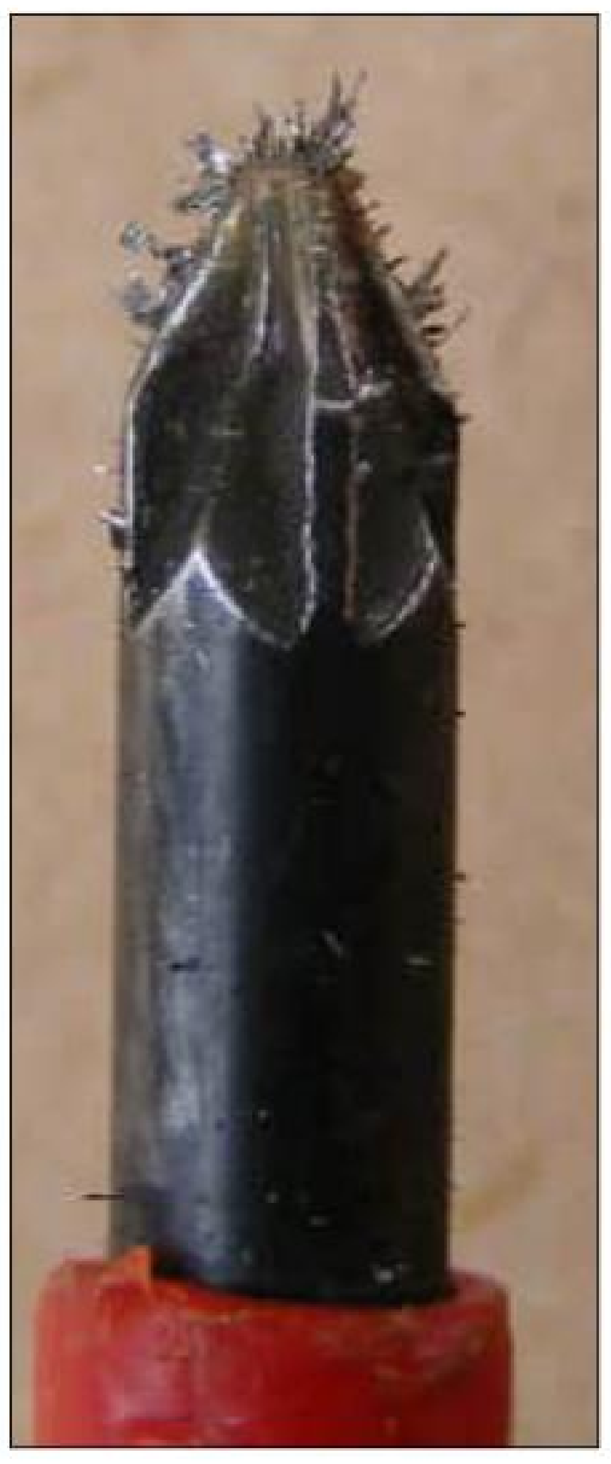


Fig.13.(left) If all else fails, drill out the screw head. Fig.14. (right) Iron filings cause havoc with crosshead screws. Keep your screwdriver clean and it's less likely to slip and ruin the head's slots.

Tool tricks

Most electronic physical work is concerned with construction. When dismantling something, different techniques are needed. Corrosion can make it impossible to undo crosshead screws with standard hand-held screwdrivers. Impact drivers that bang the screw round can sometimes work, but the downwards pressure and noise can be injurious to hands and ears. And the screw head often ends up being chewed and mangled. When this happens, pliers can be used to grab the screw head, as shown in Fig.12. Often the result of all the bashing about is the head shears off. If decapitation is a risk then it's best to drill out the screw head before this happens, as shown in Fig.13.

Another thing to watch out for is the iron filings that build up when dealing with old screws. When these stick to the screwdriver tip (Fig.14) the bit can jump out, further mangling the screw head. Keep pulling the filings off as you go.

A good tip if you want to unsolder large items, such as the gold plated connectors in Fig.15, is to use a paint stripper gun. Remember, with demolition it doesn't matter if you burn the PCB!

Pulled chips

In the early days of electronics, many chips were put in sockets, as shown in Fig.16. So the first thing to do with old equipment is to remove these ICs since there's a profitable market in 'pulled chips'. It's worth remembering that a common problem with socketed chips is that they tend to work loose and corrode over time, which reveals an important failure/repair mode. I've often found that just wiggling chips in their sockets is good way to get failed mixer channels working again.

Old TL072 op amps have proved to be very reliable and have become expensive. All the mixing desk BiFET audio op amps were pulled and sold to a guitar pedal maker.

I also found Solid State Music SSM-2015 chips (see Fig.17), which were the first decent integrated microphone pre-amp. Their designers pioneered techniques used in modern devices, such as the THAT 1570. Since the performance of the SSM-2015 is almost as good, they still demand excellent (for the seller!) prices.

No wall-warts here

While the Scorpion mixers have to go, their power supplies (Fig.18) were very well made, with dual 18V rails, 10A positive and 5A negative, so I decided these were worth keeping. They also provided an output giving +48V at 1.5A for phantom power. These were solid PSUs that fitted 2U racks with massive toroidal transformers, big heatsinks and no fans. The only thing wrong was a blown 48V voltage regulator, a LM317K HV, the unobtainable high voltage TO3 version. This was replaced with a standard LM317K with added protection Zener diodes (Fig.19). Modern electronics have plastic switch-mode power supplies which only last a few years. These old linear rack-mount PSUs can be repaired forever.

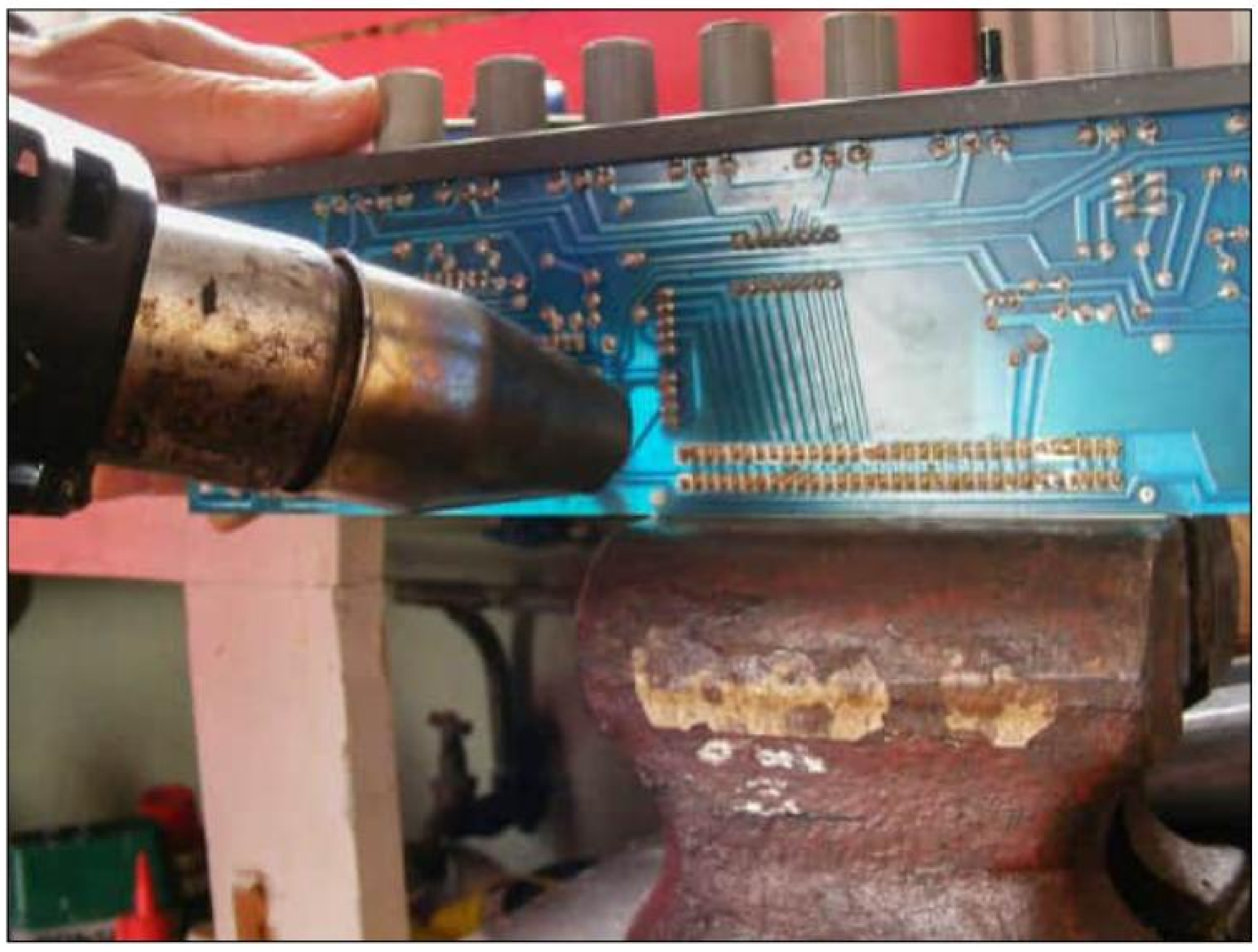


Fig.15. Unsoldering large multi-pinned components, such as this DIN connector, can be accomplished using a hot air gun. It wrecks the board though.

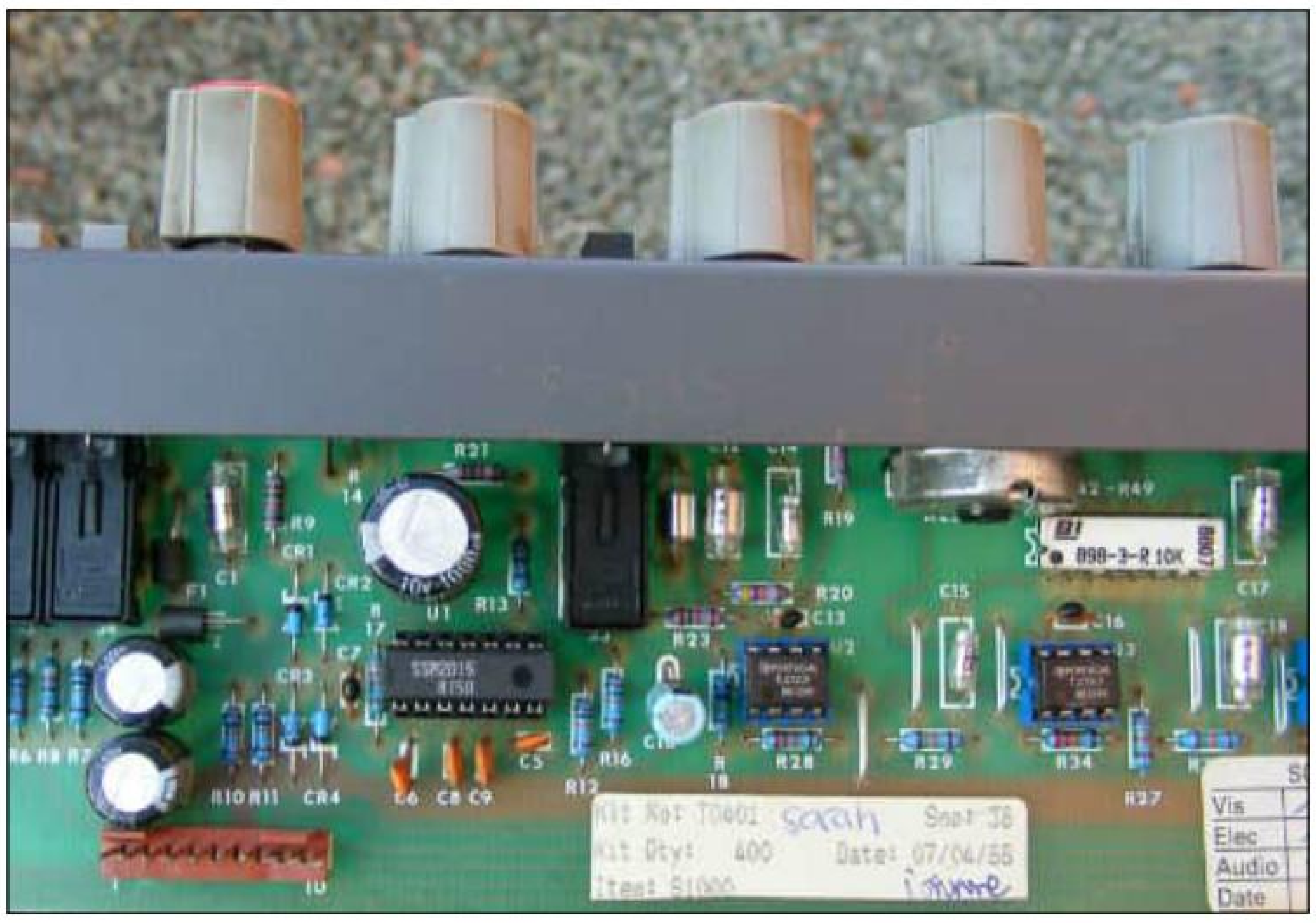


Fig.16. Like most old professional audio gear, the Scorpions chips were in sockets. It was later found the sockets were less reliable than analogue small-signal chips. However, it does make for easy removal and there's little market for unsoldered devices.

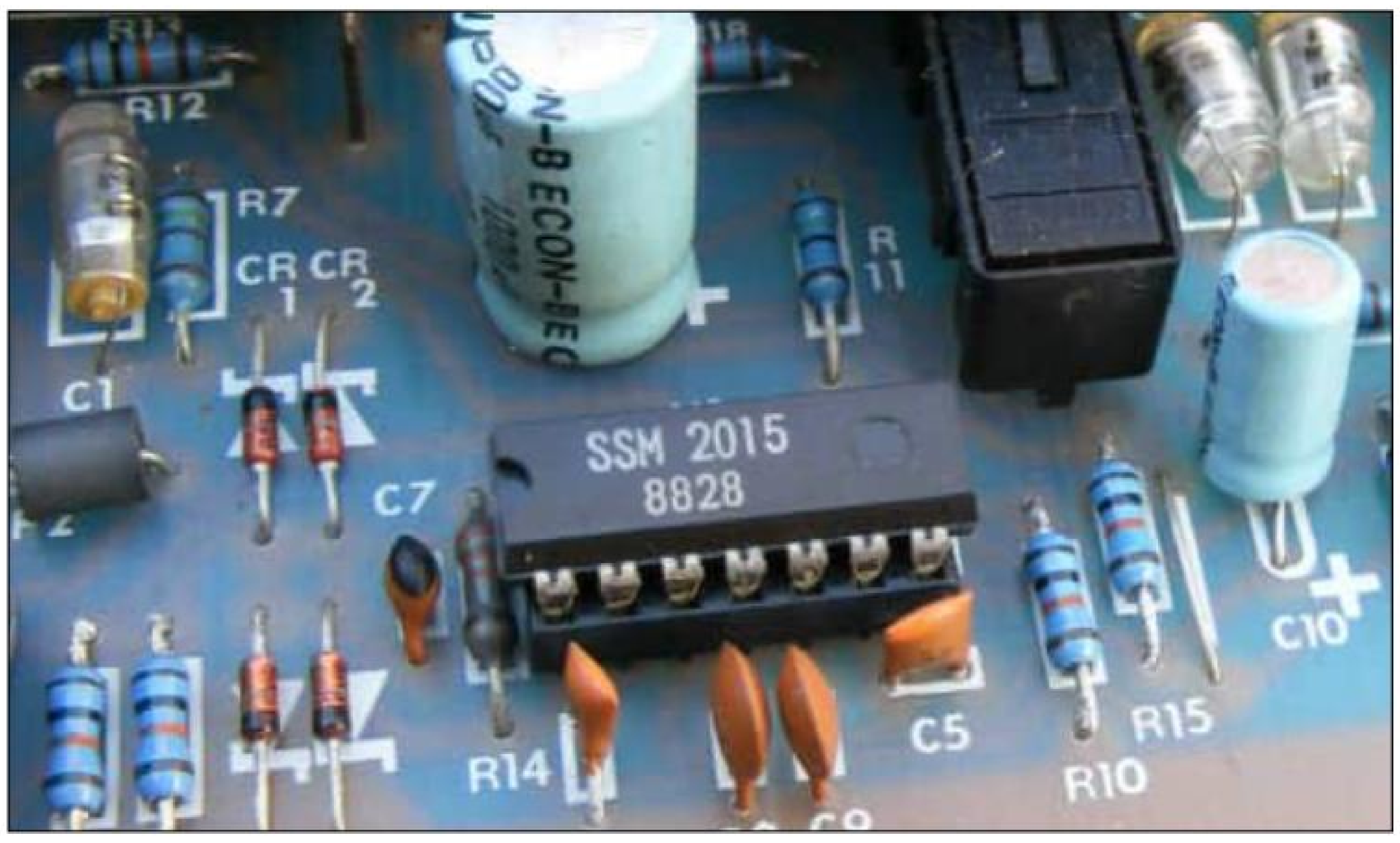


Fig.17. The SSM2015 mic pre-amp chip. This was better than the discrete circuits at the time. It is sought after since it is used in top mic pre-amps such as the Symetrics SX202.

Back to the potting shed

At first sight I was dismayed to see the desks used Omeg pots (Fig.20), possibly the old version, which I don't like. However, I was lucky; most were the current long-lasting polymer track types, which are useful. Only the gain and the sweep frequency controls were the older Radiohm versions which go scratchy.

Cleaning up

The mixing desks were truly disgusting with years of sticky 'matter' coating the front panels and knobs. The only way to clean a front panel is to pull the plastic knobs and buttons off first, undo the pot nuts, take the PCB out and wash it in the sink (Fig.21). The plastic bits can then be washed in the dishwasher in a stainless steel mesh tray, as shown in Fig.22. Experience has taught me that you have to use expensive Fairy Platinum dishwasher tablets, cheap cleaners won't do the job. The difference the cleaning makes is shown in Fig.23.

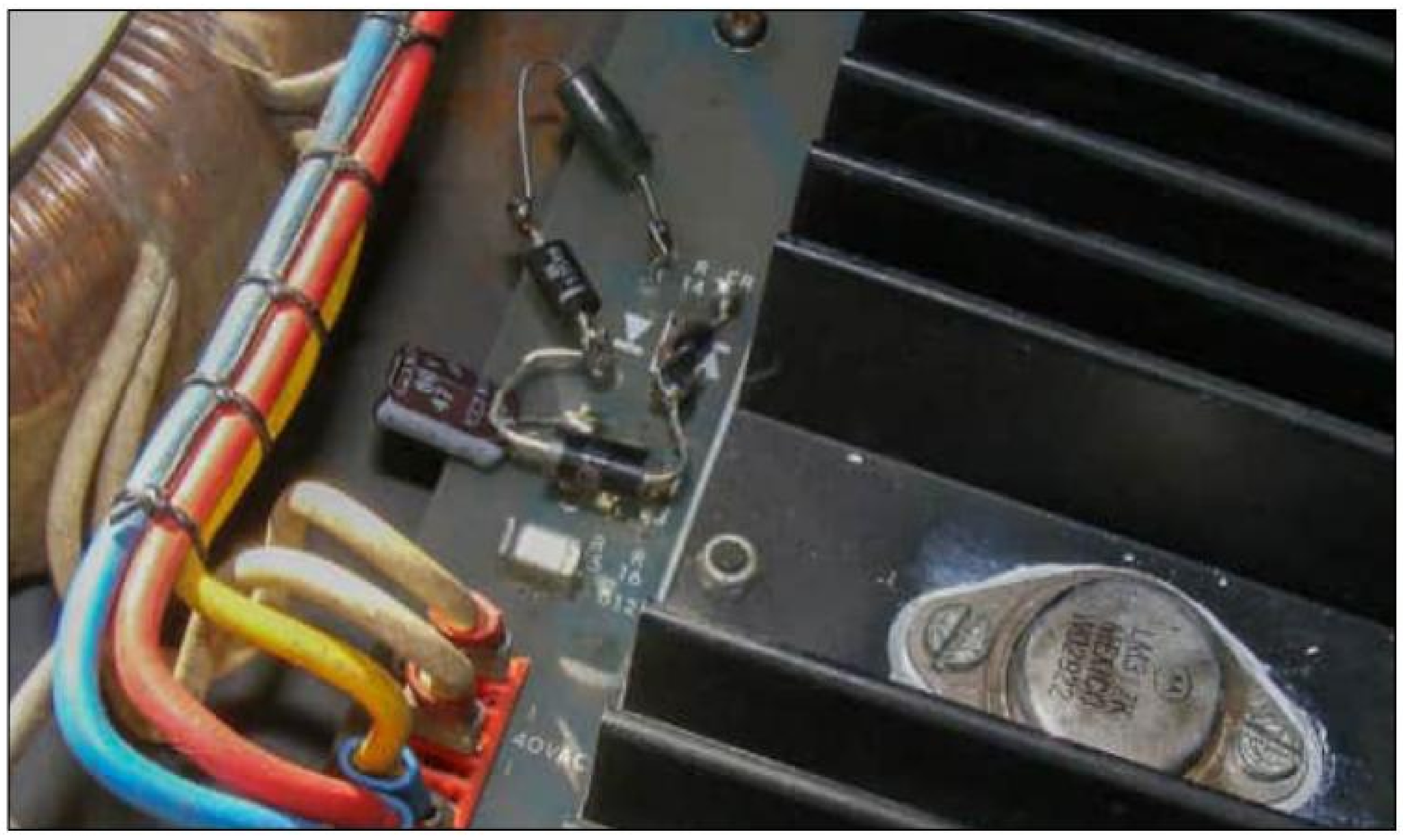


Fig.19. Using a standard LM317K regulator IC to replace the obsoleted high-voltage version. Note the extra protection components added.

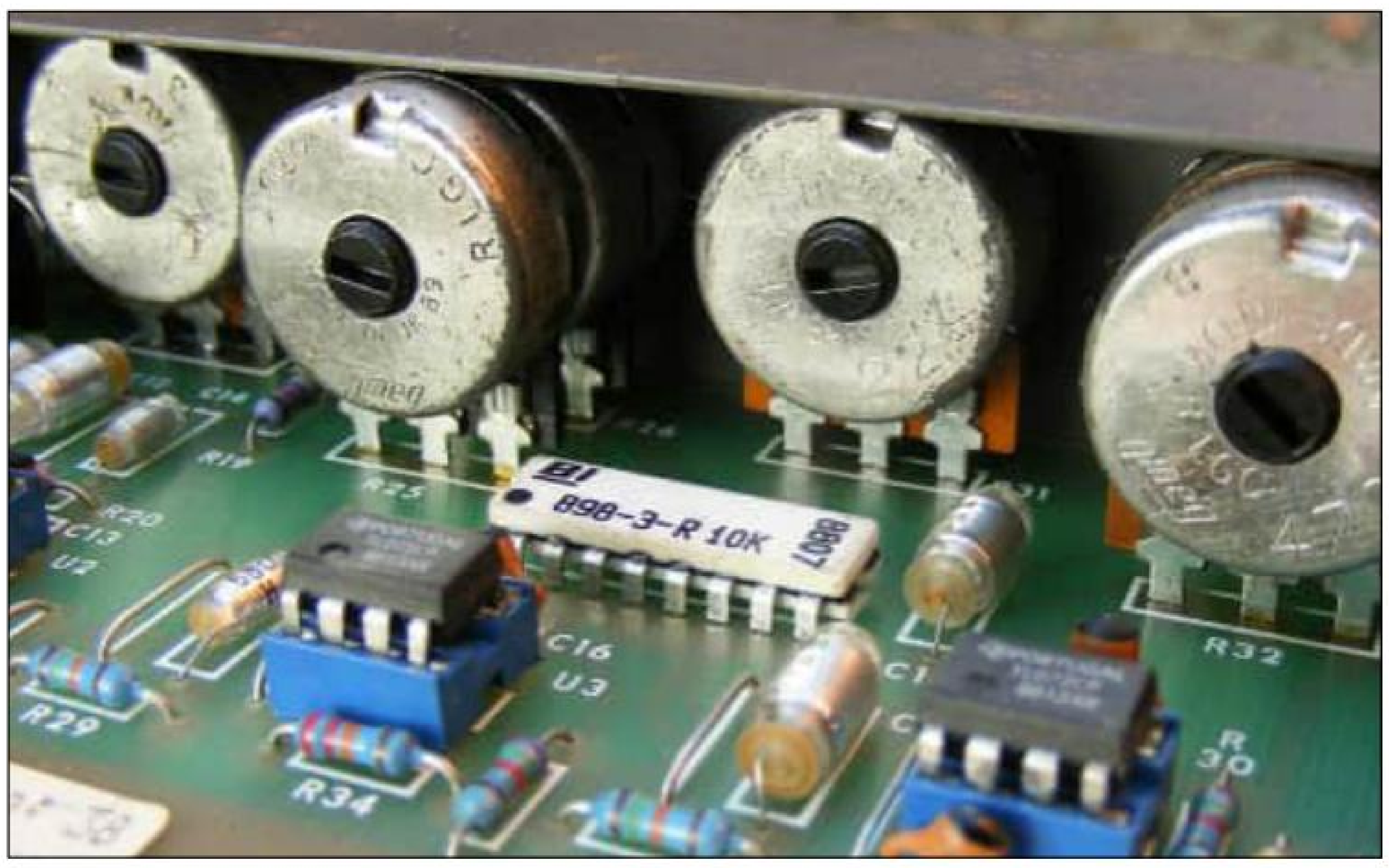


Fig.20. Omeg pots – a potpourri of old scratchy devices and new polymer ones. The scratchy ones were the frequency sweep controls (470kΩ anti-log). I may replace these someday, but because they are not moved much in a performance, it's not too critical.

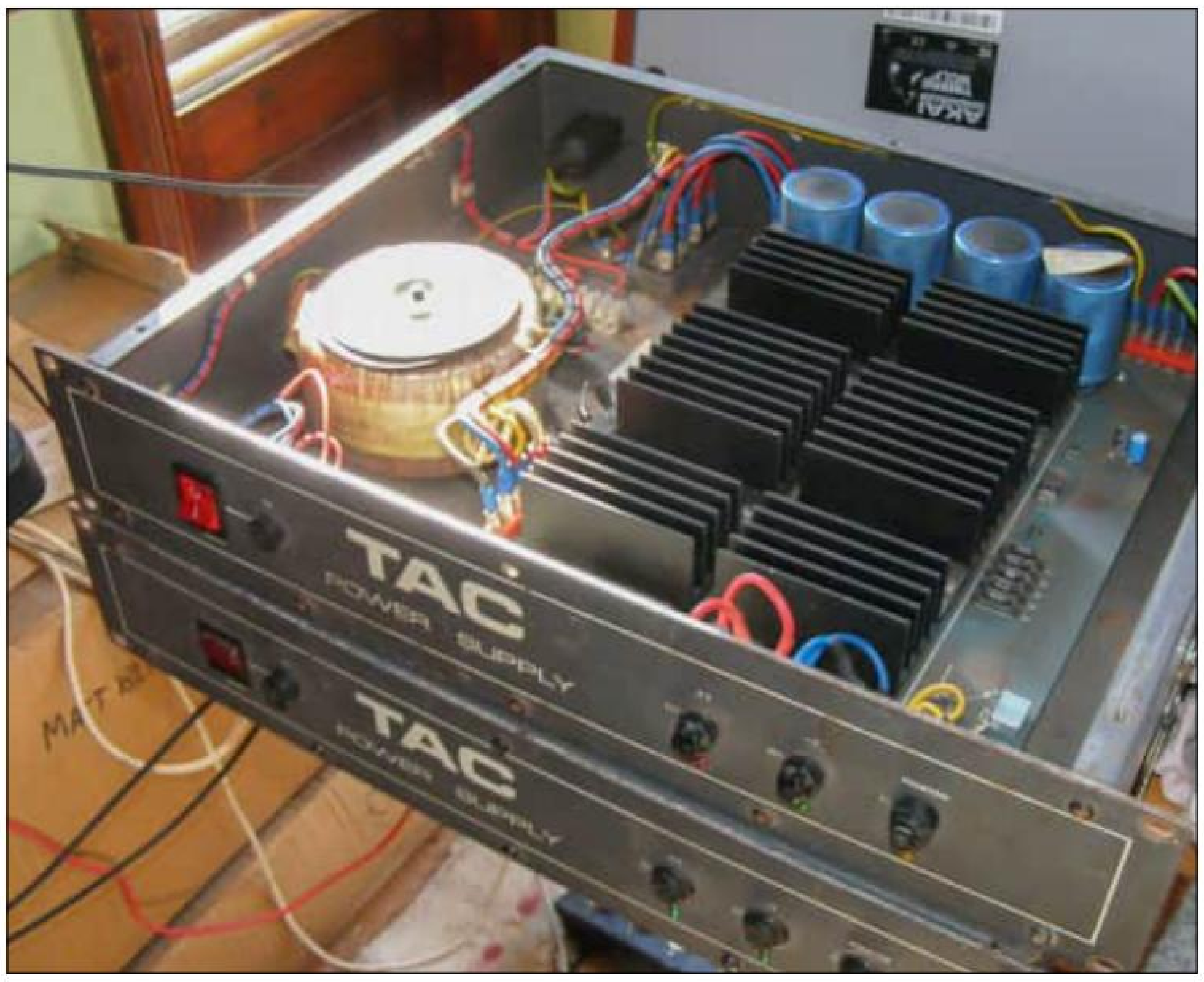


Fig.18. Scorpion power supplies – a solid, long-lasting, linear design.

Repurposing

A popular use of old mixer channels is to make stand-alone channel strips to be used as mic pre-amps for digital audio workstations. Many are sold mounted in a 1U rack case incorporating a power supply. I'm not very keen on this since the panel sliding pots are then sideways and the equaliser (EQ) controls go down in frequency from left to right. However, it can be profitable, with single channel strips fetching £50. Unfortunately, my Scorpion mixer channels were too long to fit in a 19 inch rack, so I had to give them a haircut and snip off the output routing end of the boards – rather brutally – as shown in Fig.24. Still, as I say above, better to be brutal and recycle rather than send to landfill.

Going to the tip

Once all the goodies had been removed from the failed mixer I broke up the frame in the garden (Fig.25) for scrapyard steel – it

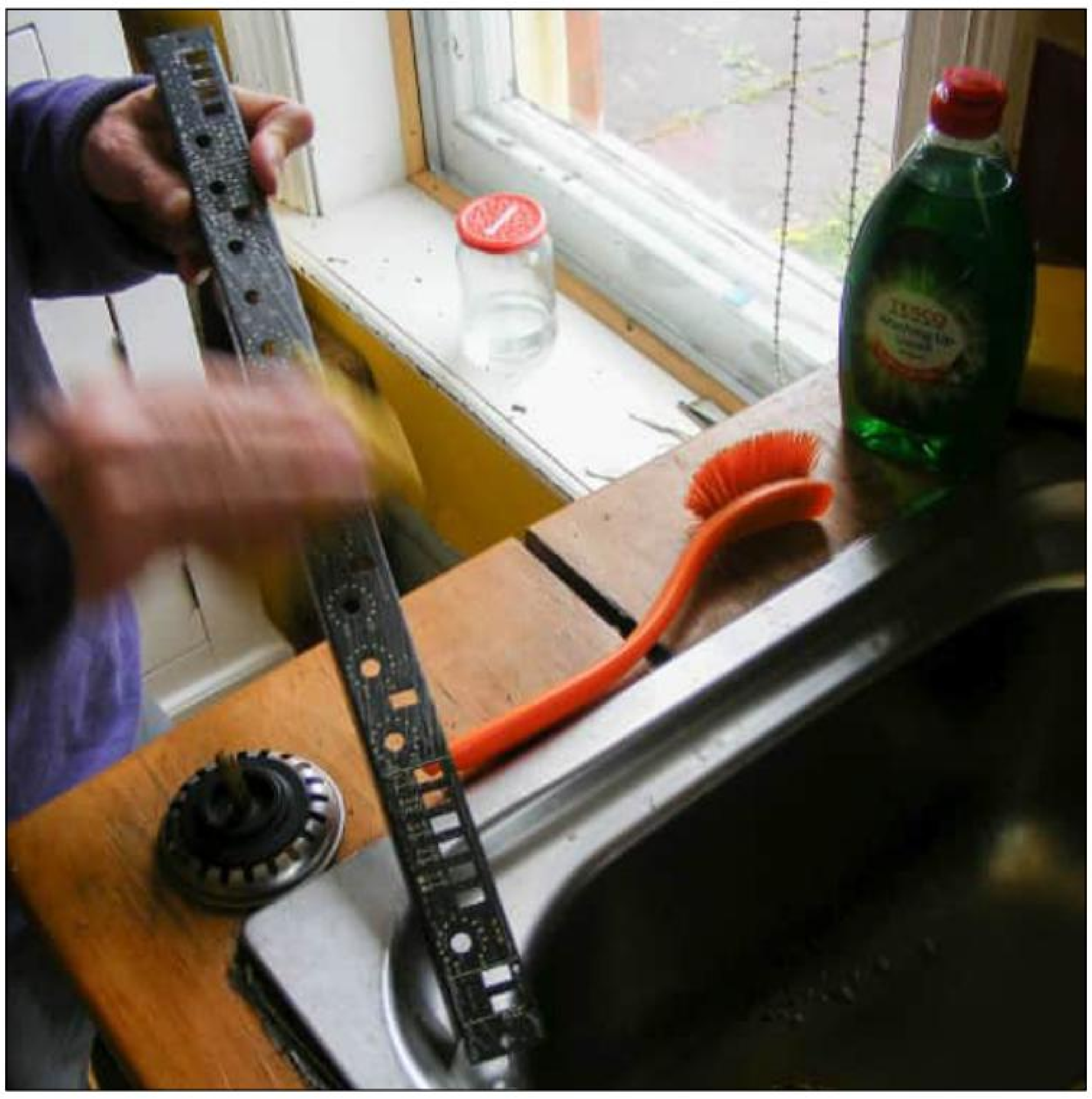


Fig.21. Washing a channel strip front panel with a lot of elbow grease!

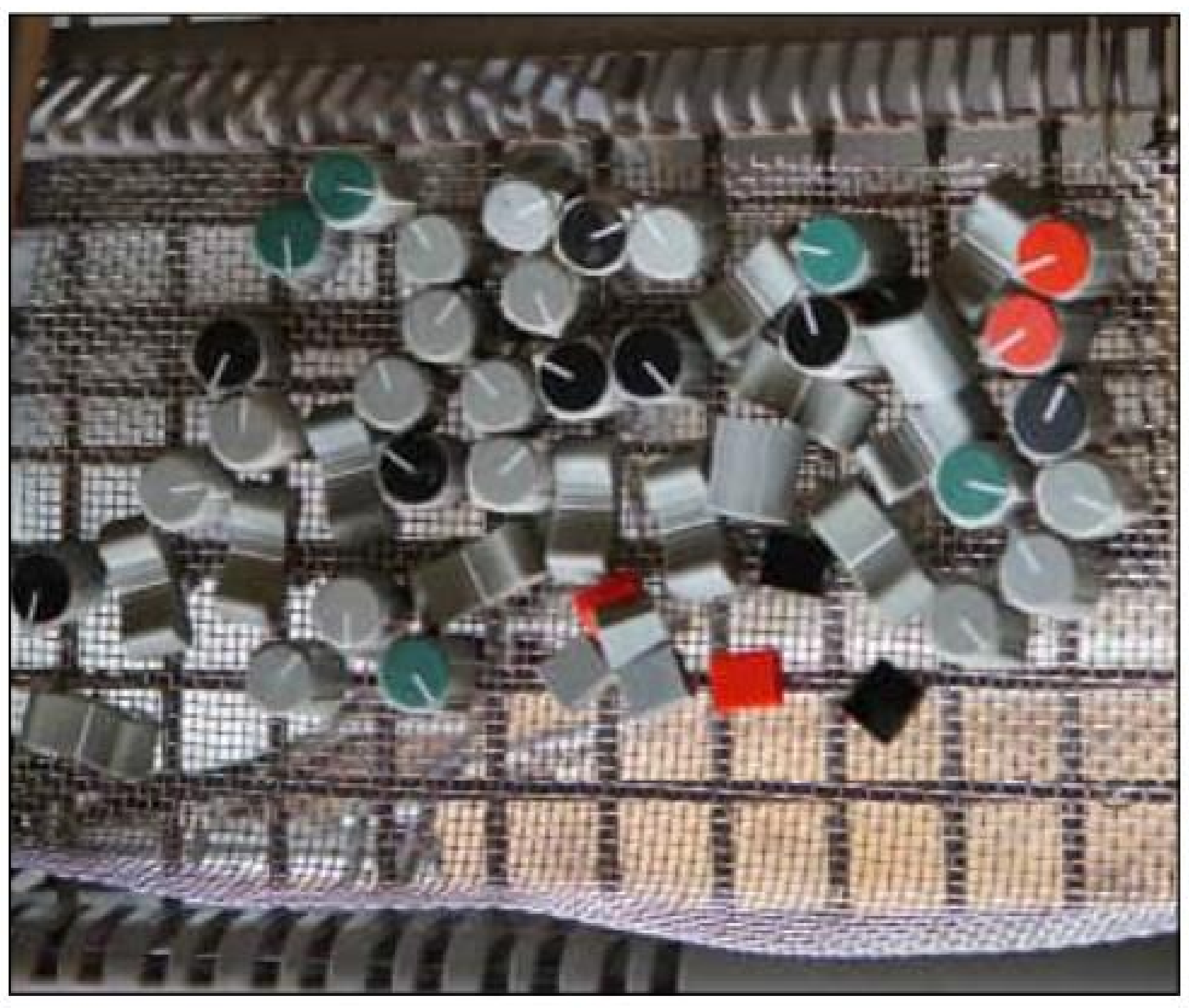


Fig.22. Plastic parts like knobs ‘scrub up lovely’ in the dishwasher.

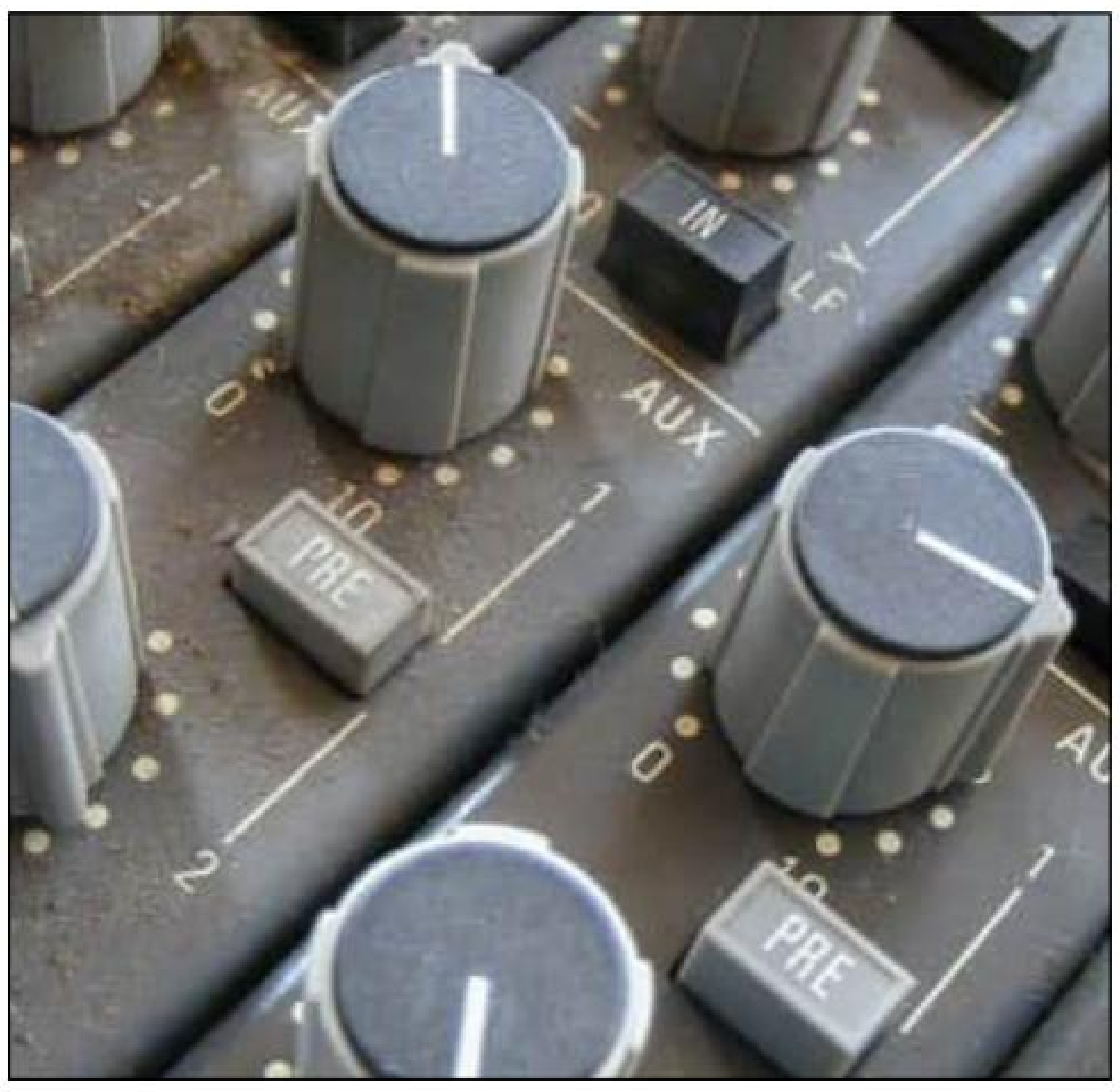


Fig.23. Comparison of clean vs. dirty. Audio gear does not sell if it’s dirty – I learnt that from second-hand car dealers.

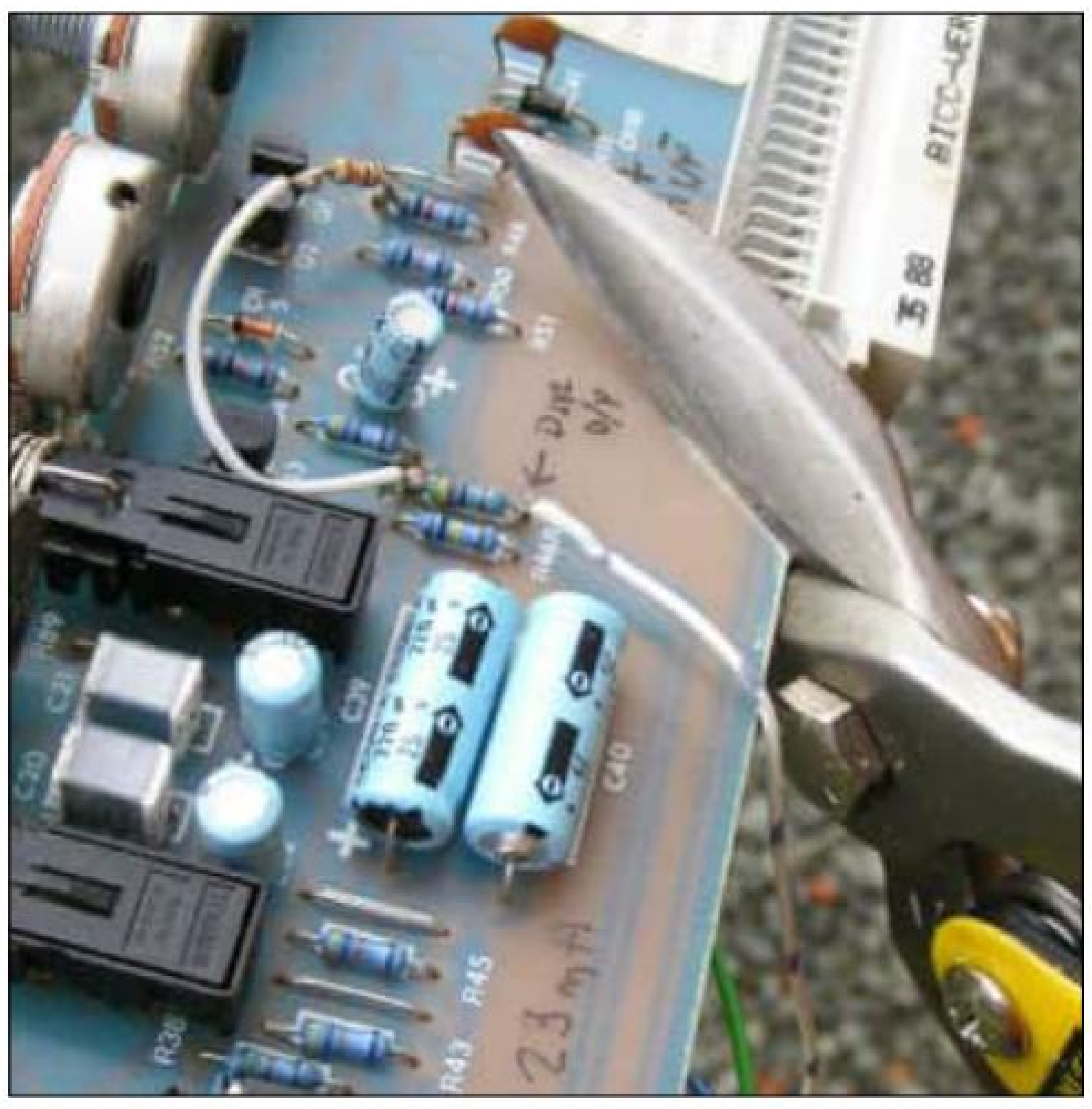


Fig.24. If it doesn’t fit, chop it with tin snips. I now have a stock of mic-pre EQ boards for all sorts of jobs that fit into the standard 19 inch rack case.

was quite a struggle! When I mentioned this to Adam Fuest, our local music producer engineer, he said the best thing about Scorpion mixing desks was the Amek frame, which I had just destroyed. Apparently, they are so strong, people put upgraded modules in them. Oh dear!

Magazines

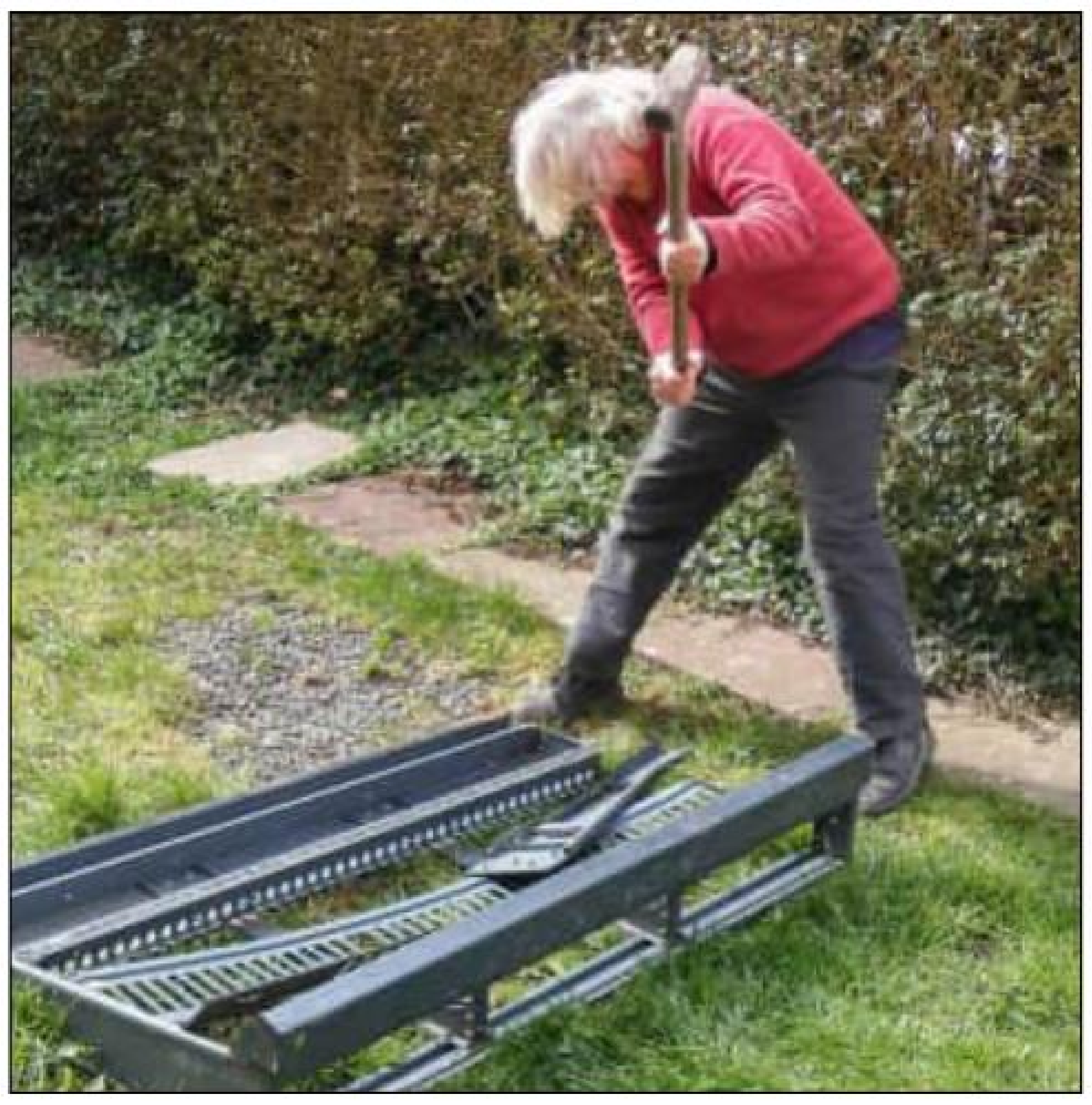


Fig.25. Wanton destruction – if you have to use a hammer, you’ve lost the plot. Use the right sized spanner. I found the right one in my socket set… after demolition.

For an old analogue person like me, most of my information is paper based. Sadly, some of this has to go as well. Luckily my collection of *Practical Electronics*, dating all the way back to November 1964 is to be entrusted to our editor’s archive. That’s seven cubic feet of Brighton real estate.

Back to mouse clicking

I’ve enjoyed using the remaining big mixer with it’s padded arm rest and ease of adjustment. It’s a superior tool for composition and live group playing compared to using a laptop. It’s also fantastic for teaching mixing techniques. But, it has to go. Anyone want to make me an offer I can’t refuse? **jrothman1962@gmail.com**

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HP6654A	PSU 0-60V 0-9A	£500
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HP83624A	Synthesised Sweeper 2 – 20GHz	POA
HP8484A	Power Sensor 0.01-18GHz 3nW-10μW	£75
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Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325
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Marconi 2955A	Radio Communications Test Set	£725
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Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 48: Long strings and sorting arrays

For those of you following the *Smart-Light Controller* (*SLC*) project, the title of this month's article may not be as expected. The reality is, when setting out on a journey of building a conceptual project, there will likely be some unexpected challenges. Here, for the *SLC*, two things cropped up while developing the final version of the of the program code. Thankfully, both challenges were not too difficult to overcome, however, we thought that they were worth writing about in a short article as they could prove to be useful building blocks in other PicoMite projects that you set out to build.

So, the two new topics we will learn about this month are long strings, and how to sort data that is stored in an array.

Too much data

Essentially, the PicoMite *SLC* communicates wirelessly to a Philips Hue hub to allow control of any of the smart lights. Most of the time, this means sending commands from the PicoMite to the Hub, for example to turn on a certain light by specifying the relevant light's ID number. However, other commands may be used to fetch information from the Hub instead, such as a list of all available smart lights that the Hub knows about. As seen previously, a list of smart lights is obtained by sending a `GET` request to:

https://hub_ip_address**/clip/v2/resource/light**

Depending on the size of your Hue setup, this could result in a lot of information being sent back to the PicoMite; for my own set-up, this was around 16,000 bytes of data.

Before we go further, it is worth giving a brief overview of the format of the data, and why there are so many bytes.

Hue JSON data

Whether data is being read from the Hub, or is being sent to the Hub, it uses a format known as 'JavaScript Object Notation' (more commonly referred to as 'JSON'). JSON is a common standard file format that uses human-readable text to transmit data. It comprises one or more 'attribute' & 'value' pairs (and/or arrays). An example of a JSON extract sent from the Hue Hub is shown in Listing 1.

If you look carefully, you will see that essentially there is a *parameter name* followed by a *parameter value* for each piece of data that is sent (formatted with lots of brackets, commas, colons and speech marks). For example, the small sample shown in Listing 1 highlights the parameter name `brightness`, which has a parameter value of `75.59`. Note that this is one of two pieces of data that belong to the `dimming` array (along with the `min dim level`), and this array is just part of all the data that relates to the smart light with ID: `"5baa****-****-****-****-******8794b6"`

The Listing 1 extract is the 'formatted' output that is reasonably easy to read. However, if you consider the unformatted raw bytes that are sent by the hub (for just the first smart light) then the JSON

Listing 1. 'Formatted' JSON data sent from the Philips Hue Hub.

```
"errors": [],
    "data": [
        {
            "id": "5baa****-****-****-****-******8794b6",
            "id_v1": "/lights/*",
            "owner": {
                "rid": "b7206469-****-****-****-******5152a4",
                "rtype": "device"
            },
            "metadata": {
                "name": "Outhouse Porch",
                "archetype": "spot_bulb"
            },
            "on": {
                "on": false
            },
            "dimming": {
                "brightness": 75.59,
                "min_dim_level": 0.2000000298023225
            },
            "dimming_delta": {},
```

Listing 2. 'Unformatted' JSON data sent from the Philips Hue Hub.

```
{"errors":[],"data":[{"id":"5baa****-****-****-****-******8794b6","id_v1": "/lights/6",
"owner":{"rid":"b7206469-****-****-****-******5152a4","rtype": "device"},"metadata":{"name"
:"Outhouse Porch","archetype":"spot_bulb"}, "on":{"on":false},"dimming":{"brightness":75.59
,"min_dim_level": 0.2000000298023225},"dimming_delta":{},"color_temperature":{"mirek":286,
"mirek_valid":true,"mirek_schema":{"mirek_minimum":153,"mirek_maximum":500}},
"color_temperature_delta":{},"color":{"xy":{"x":0.4074,"y":0.3929},"gamut":{"red":{"x":0.6915
,"y":0.3083},"green":{"x":0.17,"y":0.7},"blue":{"x":0.1532,"y":0.0475}},"gamut_type":"C"},
"dynamics":{"status":"none","status_values":["none","dynamic_palette"],"speed":0.0,
"speed_valid":false},"alert":{"action_values":["breathe"]},
"signaling":{"signal_values":["no_signal","on_off","on_off_color","alternating"]},
"mode":"normal","effects":{"status_values":["no_effect","candle","fire","prism"],
"status":"no_effect","effect_values":["no_effect","candle","fire","prism"]},
"powerup":{"preset":"powerfail","configured":true,"on":{"mode":"previous"},
"dimming":{"mode":"previous"},"color":{"mode":"previous"}},"type":"light"}
```

data will look something like the data in Listing 2.

You can see from Listing 2 that where there are more than just a handful of smart lights in a setup, the amount of data that the Hub will output (in response to specific commands) can become very large, very quickly.

Buffer-size

In our *SLC*, when certain commands (ie, requests) are sent from the PicoMite to the Hub, it is the ESP32 Wi-Fi module that will wirelessly receive the JSON data (ie, response) from the Hub. This data will be temporarily stored in the ESP32's internal buffer (something that doesn't concern us), and simultaneously the ESP32 will send out this buffered data (one byte at a time) from its serial output pin (Tx). The PicoMite simply needs to have a serial COM port configured so that any data received from the ESP32 module on the PicoMite's input pin (Rx) will automatically be stored in the PicoMite's COM port buffer. Put simply, the PicoMite's COM port buffer stores the data sent by the Hub (via the ESP32) and makes it available for processing by the program code.

In theory, all we need to do is ensure that when we configure the COM port in MMBASIC, it is given a large enough buffer size to hold all the data. However, this buffer size will vary considerably and is ultimately dependent upon the number of smart lights in the setup, but for now, let's go with the fact that the PicoMite has enough memory to allow us to configure a large enough COM port buffer. Normal practice is for the program code to then remove any data stored in the PicoMite's COM port buffer and load it into a string variable so that the data can be processed.

Processing JSON data

The concept for processing the JSON data is relatively straightforward. Begin by copying the contents of the COM port buffer into a string variable (let's call it `Buff$`). Next, look for the first occurrence of the required parameter name; this can be achieved by using the `INSTR` function. The associated parameter value will be located immediately after the parameter name (as can be seen in the above JSON extract) – hence the value can be extracted by the program code by using the `MID$` function, ideally into an array. Once the parameter value has been extracted, delete all the characters in `Buff$` up to the end point of the parameter value and then simply repeat the process multiple times for each piece of information (and for each smart light) until the end of the JSON data (ie, the end of `Buff$`) is reached.

Note that this method requires all of the JSON data contained in the COM port buffer to first be copied into a string variable so that the program code can use MMBASIC's various string manipulation commands, along with some neat tricks, to extract the required data. However, the maximum size (ie, length) of a string variable is limited to just 255 bytes (characters), and this is nowhere near big enough for what we need. So, our first challenge is how to store data in a string variable that allows for more than 255 bytes so that we can process it in the method outlined above.

Thankfully, MMBASIC incorporates functionality for *long strings*, and as the name implies, this allows for many more characters to be stored. In fact, long strings are limited in size only by the available RAM in the PicoMite. (Use the `MEMORY` command to check how much RAM is available). Therefore, a single long string is perfect for our application here as it will be able to store the complete JSON message that is received into the PicoMite's COM port buffer. Before we continue, there are a few things that we first need to understand when using long strings.

MMBASIC long strings

The ability to store a lot more than 255 characters in a long string has many practical uses, all of which allow the contents of the string to be manipulated. In our *SLC* we will use a single long string to store the complete JSON response from the Hue Hub so that the required information about all the smart lights can be extracted (name, ID, status and brightness). In a similar manner, a long string could be used to store serial data sent from other hardware devices such as a GPS receiver. In this case, we could store all of the NMEA sentences that a GPS module outputs, and then relevant data, such as longitude and latitude could be extracted by using the same technique that we will be describing shortly. So, as you can see, this is valuable technique to master.

However, be aware that we can't use the usual string manipulation commands that we are familiar with, such as `LEFT$`, `RIGHT$` and `MID$` as these only work on standard string variables. In their place, MMBASIC has an extensive set of dedicated commands and functions used purely with long strings.

Declaring a long string

Before we can use a long string, we must first declare it, in other words, the equivalent of `DIM Buff$` which would be used for a standard string declaration. Warning! The next couple of sentences may sound confusing, but just go with it for now; the example given below will help you make sense of it.

A variable for holding a long string must be defined as an integer array (even though it will be storing string data). The array must be single-dimensional, with the number of elements set to the number of characters required for the maximum string length divided by eight. The reason for dividing by eight is that an integer occupies 8 bytes (but we are not storing integers, we are storing characters). Basically, this is the way that the firmware needs to handle the data internally, and it is used to reserve memory for holding the contents of the long string.

Let's use an example to help clarify this. For a standard string (let's stick with calling it `Buff$`), we would make the declaration by using:

```
DIM Buff$
```

or

```
DIM STRING Buff
```

However, to declare the equivalent as a long string (with the ability to store a maximum string length of 22,000 characters) we would simply use:

```
DIM INTEGER Buff(22000/8)
```

Using this declaration will create an empty (zero length) long string, with the name `Buff`. Now that we know how to declare a long string, let's look at the dedicated long string commands that are available for us to use.

Long string commands

All long string commands are easy to spot because they begin with `LONGSTRING` and are then followed by a specific word, which in most cases is self-explanatory. Rather than going into the specific details of each command, below is a table of all the `LONGSTRING` commands (along with the required parameters, and a brief description). Further details can be found in the *PicoMite User Manual*. Note that those shown in bold are ones that we will be using in our program-code.

Long string functions

In addition to the 15 long string commands there are four long string functions, also shown in the table below.

It must be stressed here that whenever a long string variable is used with one of the dedicated long string commands or functions, it should be sent as the name of the long string, followed by empty brackets. For example, to empty the long string named `Buff`, you would use the long string `CLEAR` command as follows:

```
LONGSTRING CLEAR Buff()
```

Now that we know how to declare a long string, and also what commands (and functions) are available to manipulate a long string, let us now discuss how we are going to extract the relevant information from the JSON data received from the Hue Hub.

Extracting the data

To demonstrate how to extract information from JSON data, we will use the first three lines of the extract shown in Listing 2. Therefore, for the purpose of this exercise, let's assume that the content of the long string `Buff()` is as follows (ie, an incomplete JSON message):

```
{"errors":[],"data":[{"id":"5baa****-****-
****-****-******8794b6","id_v1": "/lights/
6","owner":{"rid":"b7206469-****-****-****-
******5152a4","rtype": "device"},"metadata":
{"name":"Outhouse Porch","archetype":
"spot_bulb"}, "on":{"on":false},"dimming":
{"brightness":75.59,"min_dim_level":
```

Let's extract just four bits of data: the ID value of the smart light, along with its name, its on-status (true or false), and finally its brightness value. First, we will use the `INSTR` function to search for the first required parameter name (in this case, `id`) along with any characters either side that are fixed. In other words, we will search for the following characters:

```
{"id":"
```

Note this is highlighted in red in the three-line extract. However, because this search string contains speech mark characters (as highlighted in purple), we must define the search string incorporating `CHR$(34)` in place of any speech mark (note: `CHR$(34)` represents the ASCII character for a speech mark). Hence, we need to search for the string:

```
"{" + CHR$(34) + "id" + CHR$(34) + ":" + CHR$(34)
```

To get the position of the first occurrence within the long string `Buff()` where this search string occurs, we will use the following long string function, and place the answer in a variable that we will call `j_ID`

```
j_ID = LINSTR( Buff(), "{" + chr$(34) + "id" +
chr$(34) + ":" +chr$(34), 1)
```

Hence, `j_ID` will contain the value `22`, which is the character position of the first character highlighted in red.

We can now use the `TRIM` command to remove all the characters from the start of `Buff()` up to the end of the

Long string commands

`LONGSTRING APPEND array%(),string$`	Append an ordinary string to a long string.
`LONGSTRING CLEAR array%()`	Empty a long string (set length to zero).
`LONGSTRING COPY dest%(),src%()`	Copy a long string.
`LONGSTRING CONCAT dest%(),src%()`	Concatenate two long strings.
`LONGSTRING LCASE array%()`	Convert a long string to lowercase.
`LONGSTRING LEFT dest%(),src%(),nbr`	Get the left *nbr* characters from a long string.
`LONGSTRING LOAD array%(),nbr,string$`	Copy characters to a long string.
`LONGSTRING MID dest%(),src%(),start,nbr`	Get characters from the middle of a long string.
`LONGSTRING PRINT [#n,]src%()`	Print a long string.
`LONGSTRING REPLACE array%(),string$,start`	Replace characters in a long string.
`LONGSTRING RESIZE addr%(),nbr`	Set the length of a long string.
`LONGSTRING RIGHT dest%(),src%(),nbr`	Get the right *nbr* characters from a long string.
`LONGSTRING SETBYTE addr%(),nbr,data`	Set a byte in a long string.
`LONGSTRING TRIM array%(),nbr`	Trim *nbr* characters from the left of a long string.
`LONGSTRING UCASE array%()`	Convert a long string to uppercase.

Long string functions

`r = LGETBYTE(array%(),n)`	Returns the value of a byte in a long string
`r$ = LGETSTR$(array%(),start,length)`	Returns part of a long string as a normal string
`r = LINSTR(array%(),search$[,start])`	Returns the position of a string in a long string
`r = LLEN(array%())`	Returns the length of a long string

search string itself. This will result in the long string `Buff()` containing the following characters:

```
5baa****-****-****-****-******8794b6","id_v1": "/
lights/6","owner":{"rid":"b7206469-****-****-****-
******5152a4","rtype": "device"},"metadata":
{"name":"Outhouse Porch","archetype":"spot_bulb"},
"on":{"on":false},"dimming":{"brightness":75.59,
"min_dim_level":
```

To do this, we use the following command:

```
LONGSTRING TRIM Buff(),j_ID+6
```

Note that here we are using the value stored in `j_ID` (from the first step) and adding '6' to it to ensure that we are removing the correct number of characters from the start of `Buff()` – in this case, 28 characters need to be trimmed.

More importantly, the parameter value (ie, data) that we need to extract is now right at the start of `Buff()`.

To be able to extract the data (in this case the ID of the first smart light), we will need to know the length of it first – or in other words, work out the position of the speech mark character highlighted in red, and subtract '1' from that value to get the length of the data. Hence, we will first need to use the `LINSTR` function to get the position of the highlighted speech mark and subtract '1' from the answer, and store the result in the variable `j_end`. This is achieved using the following:

```
j_end = LINSTR(Buff(), chr$(34), 1) - 1
```

Finally, we can use the `LGETSTR$` function to extract the required number of characters (the length of data as stored in `j_end` – in this example the length is 36 characters) and store the result in a standard string; in this case `L_ID$`. The following shows how to do this:

```
L_ID$ = LGETSTR$(Buff(), 1, j_end)
```

The above process can be repeated in turn for each piece of data you wish to extract. Essentially you are repeatedly performing the following steps:

1. Search for the relevant parameter name, including any 'fixed' characters up to the start of the parameter value, by using the `LINSTR` function.
2. Remove all the leading characters by using the `LONGSTRING TRIM` command.
3. Search for the character immediately after the required data to be extracted by using `LINSTR` to determine the data length.
4. Use the data length from step 3 to extract the required data by using the `LGETSTR$` function.

The above is the concept for extracting information from the JSON data. In the final version of our program code, we use a loop (with a counter) to extract the required data into various arrays. So, rather than `L_ID$` as used above, we will be using `L_ID$(`*`counter`*`)`. This will allow us to more easily reference each smart light – more on this next month.

Sorting Data in an array

In the final version of the *SLC* code, we will be displaying a list of all available smart lights so that the user can select which one to control. To make it easier to find a specific smart light, it makes sense to display the list of their names sorted alphabetically. To achieve this, we will now discuss the MMBASIC `SORT` command.

Let's assume that we have all the smart light names extracted from the JSON data stored unsorted in an array named `L_Name$()`. For this example, let's use the following sequence of names (taken from my Hue setup):

```
L_Name$(1)="Outhouse Porch"
L_Name$(2)="Dining Room Light"
L_Name$(3)="Dressing Table Striplight"
L_Name$(4)="Hut Light"
L_Name$(5)="Water Feature"
L_Name$(6)="Phil's Lamp"
L_Name$(7)="Globe Light"
L_Name$(8)="Girl's Room"
L_Name$(9)="Jenson's Light"
L_Name$(10)="Flood Light 2"
```

Rather than re-sequence this list back into the `L_Name$()` array, we will use the `SORT` command to generate a list of sorted 'index' numbers, and store this information in a new array that we will call `L_SortIndex%()`

For this example, we will also store the sorted list of names in a new `L_Temp$()` array too. First, we need to declare the two new arrays with:

```
DIM L_SortIndex%(10)
```

and

```
DIM L_Temp$(10)
```

Note that they must both be exactly the same size as the `L_Name$()` array that we wish to sort (in the above example the `L_Name$()` array has 10 elements). Next, we need to copy the contents of the `L_Name$()` array into the `L_Temp$()` array as follows:

```
FOR i = 1 to 10
  L_Temp$(i)=L_Name$(i)
NEXT i
```

Finally, to sort the data, we use the `SORT` command in the following manner:

```
SORT L_Temp$(),L_SortIndex%()
```

This will result in the content of each array (shown below just for element 1) as follows:

`L_Name$(1) = "Outhouse Porch"`	(unchanged original name)
`L_Temp$(1) = "Dining Room Light"`	(sorted alphabetical name)
`L_SortIndex%(1) = 2`	(index number from `L_Name$()` array that is first name alphabetically)

For completeness, the contents of the `L_SortIndex%()` array will be as follows:

```
L_SortIndex%(1) = 2
L_SortIndex%(2) = 3
L_SortIndex%(3) = 10
L_SortIndex%(4) = 8
L_SortIndex%(5) = 7
L_SortIndex%(6) = 4
L_SortIndex%(7) = 9
L_SortIndex%(8) = 1
L_SortIndex%(9) = 6
L_SortIndex%(10) = 5
```

As a quick exercise, check the mapping of the values stored above from the `L_SortIndex%()` array, and look up the corresponding element from the `L_Name$()` array; and you will see that the names are sorted alphabetically.

To display the sorted list of smart lights in code, we have two options. The more obvious option is to use the following:

```
FOR i = 1 to 10
  PRINT L_Temp$(i)
Next i
```

However, we will use the following option instead:

```
FOR i = 1 to 10
  k=L_SortIndex%(i)
  PRINT L_Name$(k)
Next i
```

Both versions display the same result, but the second version allows other data stored in other arrays such as `L_Status$()`, `L_Brightness$()` and `L_ID$()` to be referenced correctly by using the index value stored in `k` (obtained from the `L_SortIndex%()` array) without having to re-sequence any of these other arrays.

Don't worry if this is getting difficult to follow, just be mindful that to display the sorted list of smart light names, we will use the second option shown above.

Demo code

To demonstrate all of the techniques that we have been discussing this month, we have created a demo program – **ExtractJSON.txt** – you can download this code from the August 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**

Load it into your PicoMite, but before running it, ensure that you edit the first few lines of uncommented code so that it can connect to your wireless network, and also set your Hub's IP address, and your unique Hub-API key.

Once you have set these required parameters, `RUN` the program and observe the information displayed on your terminal screen.

After a short delay, you should see a list of all your Hue smart lights (and any smart sockets) – see Fig 1. For each smart light that the Hue Hub knows about, it will display the unique smart light ID, its current status and if the status is 'ON'. Then it will display the current brightness as a percentage (but only for dimmable smart lights). Finally, the name of the smart light (or smart socket) is also shown (as configured in the Hue App).

Note that the list of smart lights (and any smart sockets) is shown twice. The first list (at the top) is displaying the smart lights in the same sequence that they are contained in the JSON file; and the second list is the same information but sorted alphabetically by smart light name.

In addition, the sorted list of smart light names is displayed on the touchscreen (this will get tidied up next month!).

Do be sure to have a look at the program code to see if you can understand how it works. You should be able to see how the topics covered this month have been used to generate the two lists of smart lights displayed in your terminal screen.

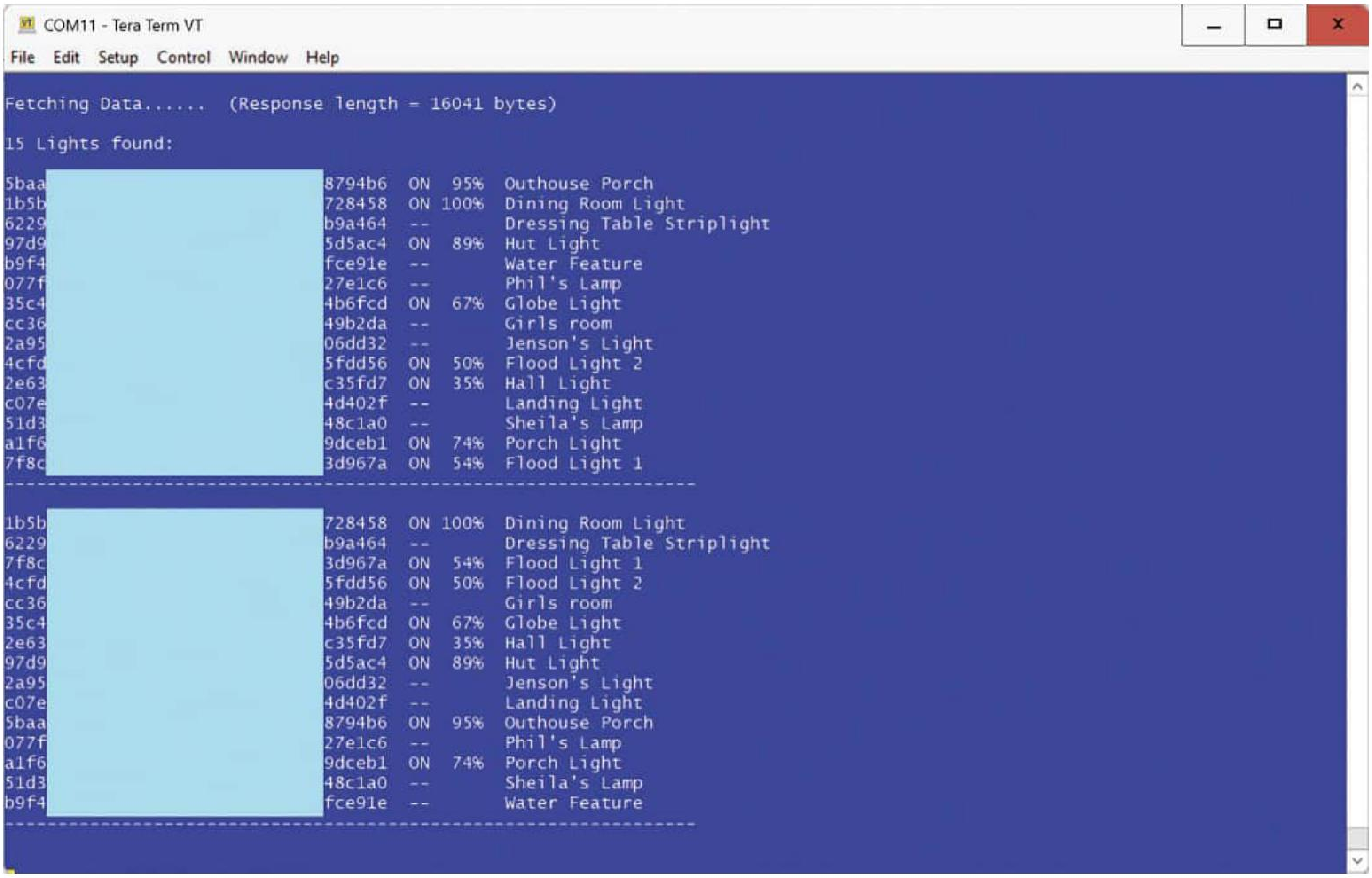
Next Time

Now that our program code can successfully extract a list of smart lights from the Hue Hub (along with the unique ID number that we will need to be able to control a specific smart light), we are able to finish the software for the *SLC*. Next month, we will discuss how the software implements the features of selecting a specific light from the list of all available smart lights, and how it then then controls it.

Until then, stay safe, and have FUN!

Micromite code

The code in this article is available for download from the August 2023 page of the *PE* website.



```
Fetching Data......  (Response length = 16041 bytes)

15 Lights found:

5baa[redacted]8794b6  ON   95%  Outhouse Porch
1b5b[redacted]728458  ON  100%  Dining Room Light
6229[redacted]b9a464  --        Dressing Table Striplight
97d9[redacted]5d5ac4  ON   89%  Hut Light
b9f4[redacted]fce91e  --        Water Feature
077f[redacted]27e1c6  --        Phil's Lamp
35c4[redacted]4b6fcd  ON   67%  Globe Light
cc36[redacted]49b2da  --        Girls room
2a95[redacted]06dd32  --        Jenson's Light
4cfd[redacted]5fdd56  ON   50%  Flood Light 2
2e63[redacted]c35fd7  ON   35%  Hall Light
c07e[redacted]4d402f  --        Landing Light
51d3[redacted]48c1a0  --        Sheila's Lamp
a1f6[redacted]9dceb1  ON   74%  Porch Light
7f8c[redacted]3d967a  ON   54%  Flood Light 1
-----------------------------------------------------------------

1b5b[redacted]728458  ON  100%  Dining Room Light
6229[redacted]b9a464  --        Dressing Table Striplight
7f8c[redacted]3d967a  ON   54%  Flood Light 1
4cfd[redacted]5fdd56  ON   50%  Flood Light 2
cc36[redacted]49b2da  --        Girls room
35c4[redacted]4b6fcd  ON   67%  Globe Light
2e63[redacted]c35fd7  ON   35%  Hall Light
97d9[redacted]5d5ac4  ON   89%  Hut Light
2a95[redacted]06dd32  --        Jenson's Light
c07e[redacted]4d402f  --        Landing Light
5baa[redacted]8794b6  ON   95%  Outhouse Porch
077f[redacted]27e1c6  --        Phil's Lamp
a1f6[redacted]9dceb1  ON   74%  Porch Light
51d3[redacted]48c1a0  --        Sheila's Lamp
b9f4[redacted]fce91e  --        Water Feature
-----------------------------------------------------------------
```

Fig 1. This month's demo program (**ExtractJSON.txt**) extracts data from the Hue Hub and displays it in two lists. The first list is unsorted, but the second list is sorted alphabetically by the smart light name. (Note that the ID numbers have been obscured for security reasons!)

AOShop

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors	
AC125, NKT214F, OC57 OC59	£1.00
Low-noise PNP transistors	
GET106	£2.50
Small power PNP transistors	
AC153, AC153K, AC188	£1.50
High-voltage PNP transistors	
OC77, CV7001, ACY20	£1.50
TO3 PNP power transistors	
OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	£2.00
AD140	£3.50
AD149 matched pair	£5.00
RF PNP transistors	
OC41, OC42, 2SA12, 2SA53,AF124, AF128, GET872A	£1.50
NPN transistors	
OC139, OC140, ASY73, AC141K, AC176K, AC176	£2.00
Diodes	
CV7049 (OA10), CG92 (OA91)	£0.50

Si semiconductors

Diodes	
ZC5800 RF Schottky	£0.20
Low-noise silicon transistors	
BFW16A, 2SC3071	£1.50
2SC2204, 2SD655	£0.50
ZTX651	£0.30
RF transistors (suitable for Theremin)	
BF199	£0.50
BF245	£0.60
Audio power MOSFETs	
Exicon 10N20, 10P20	£6.50
Hitachi 2SJ99, 2SK343	£3.50
Hitachi 2SJ 50, 2SK135	£7.00
Hitachi 2SJ56, 2SK176	£8.50
JFETs	
BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176	£1.00
MOSFETs	
ZVP2106A	£0.30
Dual-gate 3SK45, BFS28	£1.50
Metal-cased transistors	
BC143	£0.35
2N1711	£0.50
BCY71	£0.30
BC109C	£0.60
Amplifiers	
TL082 dual JFET input op amp	£0.25
LM318 high-speed op amp	£0.35
µA709 metal-cased op amp	£2.00
5534H metal-cased op amp	£3.00
LM384, TDA2030A	£1.50
TAA435 (power amp driver)	£1.20

Synthesiser ICs

That/dbx 2180 VCA/VCF	£6.00
CA3080 VCA/VCF (vocoder)	£2.80
CA3082 VCA/VCF	£4.00
LM13600/ LM13700 VCA/VCF	£2.00
CA3086 transistor array	£1.00
PT2399 echo/delay	£1.50

Dual transistors	
2N2639, 2N2223, 2N2910 (NPN)	£4.00
E401 (JFET)	£4.00
DMMT3904/6	£0.50

Loudspeakers

PE Mini-Monitor	
Volt PE165 6.5-inch woofer (each)	£85
Morel MDT29 tweeter (each)	£25
Kit *pair* of PE165/MDT29 plus Volt crossover parts and PCBs	£299
Monacor DT-28N tweeter (each)	£45
Vifa 19mm BC20SC15-04 tweeter (each)	£15
Volt PE110 5-inch woofer (each)	£75
Volt crossover inductors	
1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	£5.85
LS3/5A transformer-core 15Ω assembled crossover board (each)	£60
Fully assembled and tested high-quality speaker prototypes – ask for details	
LS3/5As and other similar speaker systems (pair)	£200-£350
Fully tested reclaimed speakers	
Vifa BC14 5-inch woofer (each)	£15
Vifa TC26 1-inch tweeter (each)	£15
Low-price speakers	
Celestion elliptical 6x4-inch 5Ω (Robert's Radio)	£3.50
Philips 4-inch 4070	£2.00
EMI 10x6-inch, 30Ω Alnico	£10
64mm 64Ω neodymium	£1.20
3.5-inch 25Ω	£3.50
5x3-inch elliptical 50Ω or 80Ω Alnico	£3.50
1.65x2.75-inch 8Ω	£1.50

Can't see what you want? Just ask – we have a huge stock of inexpensive high-quality parts!

Capacitors

Note '10/63' denotes '10µF 63V'.

Polyester	
3.3/100, 4.7/250, 4.7/63	£1.00
5.6/63, 8.2/63, 10/63	£2.00
Mullard 'Mustard' C296 0.22/400	£2.00
Polycarbonate	
Axial 2.2/63 1%, 4.7/160, 6.8/63	£1.00
Radial	
6.8/160V, 10/63	£2.00
Reclaimed 22/63	£2.00
Polystyrene	
Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63	£1.00
RIFA 1% 100nF/100	£2.00
Suflex 2.5% 10nF/63 (rad. or ax.)	£0.50
Radiation resistant	
Siemens cellulose acetate MKL 2.2/25	£0.80
Electrolytic – Mullard blue 017 series	
10/25, 22/25, 100/10	£0.50
150/40, 470/40,1000/40	£1.00
Tantalum – metal cased	
22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	£2.00
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	£1.25
4.7/50, 6.8/35, 10/25, 10/35, 22/15	£1.00
Moulded-case tantalum	
Kemet axial 6.8/10	£0.30
Kemet radial 33/10	£0.40
STC radial 100/20	£1.50
Tantalum bead	
22/50	£1.00
470/3	£2.00
680/6.3	£3.00
Wet tantalum	
220/25 axial	£3.20
Castanet button 140/30, 470/3	£3.20
Hughes 540/10	£3.20
Bipolar	
Hermetic bipolar tantalum 16/35	£3.20
Callins Elcap wet aluminium 10/50	£0.50
Philips solid-aluminium (axial) 121/123	
47/16	£1.00
330/6.3	£2.00
100/35	£4.00
Philips Pearl 122 series (radial)	
10/16	£0.30
10/25	£0.50
Silvered mica (radial)	
4.7nF/500 5%	£1.00
Trimmer capacitors	
Vishay plastic-film 4-40pF	£0.80
Vishay plastic-film 5.5-45pF	£1.00
Vishay plastic-film 5-80pF	£1.20
Vishay plastic-film 10-250pF	£2.00
Mica 1-12pF, 2-40pF	£1.00

Audio transformers and inductors

Eagle transformers	
LT44, LT722 driver, LT700, LT723 500Ω output	£2.50
LT30 500mW output	£3.50
Repanco	
T/T3 splitter transformer	£4.00
CH2 5mH RFC	£2.00
Balanced output transformer	
Vigortronix 600Ω VTX-101-007	£10
Vigortronix 600Ω VTX-101-3001	£10
Vigortronix 600Ω VTX-101-3002	£15
Gardners 150Ω	£10
Reclaimed BBC LL74/MPC nickel core 600Ω	£12
Reclaimed mic input transformer	£15
Inductors	
82µH, 4.7mH, 100µH, 270µH	£2.00
7-inch ferrite rod with MW and LW windings	£3.00

Special resistors

Bourns wire-wound trimmer 5kΩ 3059 JM panel-mount	£2.00
Thermistor RA53, A13	£4.00
Thermistor CZ1, CZ6	£1.50
Holco H2 2.2MΩ 1W, 1%	£1.00
Welwyn 1GΩ 2W	£1.00
Allen Bradley 1.2kΩ 2W C-comp	£1.00

Lots of big valve resistors available.

Potentiometers

Bourns 81	
25kΩ lin cermet	£2.00
25kΩ lin conductive plastic	£3.00
Plessey moulded-track	
5kΩ log with switch	£3.00
50kΩ A/log	£3.00
Mil 250kΩ lin dual	£5.00
Alpha	
16mm 4.7kΩ A/log	£0.80
220kΩ A/log	£0.80
10kΩ lin centre-detent dual-gang	£1.50
Allen Bradley J series/Honeywell 10kΩ lin 1 million cycles	£5.00
Blore Edwards AB 45 dual 5kΩ A/log with switch	£3.50
Alps RK9 dual-gang 5kΩ RD law	£4.00
BI P260 500kΩ log conductive plastic 1 million cycles	£3.00
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	£8.00
Mil Spec hermetic 10Ω	£8.00

Miscellaneous

Theremin Clearance Sale!	
Elysian Theremin MIDI box	£300
PCBs	
Pocket Theremin (*EPE*, 1996)	£4.00
Elysian Theremin (*EPE*, 1996)	£12
Synth VCF, VCO (*EPE*, 2017)	£3.00
48V PSU (*EPE*, 2019)	£3.00
Relays	
STC hermetic 4190 24V DPDT	£4.00
Switches Blore Edwards/Plessey	
MH1 4-pole 3-way	£3.00
Elma 01 2-pole 6-way	£6.00
3PDT guitar pedal stomp switch	£2.50
Valves	
EC88, PCL84	£3.00
Robert's Radio modules	
Tuners LP1169, LP1179	£7.00
IF strip LP1171	£7.00
Knobs – large Bakelite	
Bulgin 1960s and Sifam 1970s	£1.50

Contact
Jake Rothman
The Old Rectory, Arlais Road,
Llandrindod Wells, Powys
LD1 5HE (visit by appointment)
+44 (0)1597 829102
jrothman1962@gmail.com

Minimum order £5.00 inc post
Quantity discounts negotiable

Payment
PayPal, cards (via phone), bank transfer, cheques (payable to 'J Rothman', UK pounds only)
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Postage
Small Jiffy bag £2.99
Small package £4.99
Big boxes and overseas at cost – ask for a quote

Practical Electronics PCB SERVICE

PROJECT	CODE	PRICE
AUGUST 2023		
110dB RF Attenuator	CSE211003	9.95
Universal Battery Charge Controller (2023 update)	14107192	9.95
Wide-Range OhmMeter	04109221	12.95
JULY 2023		
Multimeter Checker/Calibrator	04107221	10.99
MIDI Spectral Sound Synthesiser (full kit – see p.25)	N/A	N/A
JUNE 2023		
Arduino Programmable Load	04105221	8.99
Buck-Boost LED Driver	16103221	8.99
MAY 2023		
Precision AM-FM DDS Signal Generator	CSE211002	14.95
Improved SMD Test Tweezers programmed PIC	0410621PIC	12.95
AO 2x-dual-to-quad through-hole (pack of five)	AO1-MAY23	6.95
AO 2x-dual-to-quad SMD (pack of five)	AO2-MAY23	6.95
AO 2x-single-to-dual through-hole (pack of five)	AO3-MAY23	6.95
AO 2x-single-to-dual SMD (pack of five)	AO4-MAY23	6.95
APRIL 2023		
500W Amplifier Module	see p.22, April 2023	
Clipping Indicator (per channel)	01112211	7.95
CD Welder Power Supply (one needed)	29103221	9.95
CD Welder Controller (one needed)	29103222	9.95
CD Welder Energy Storage module (several needed)	29103223	7.95
AO Universal Dual Op Amp Board	AO1-APR23	9.95
AO Stereo RIAA precision passives kit for dual op amp	AO2-APR23	8.95
MARCH 2023		
Pico BackPack	07101221	9.95
Semaphore Signal (controller)	09103221	7.95
Semaphore Signal (blade)	09103222	5.95
FEBRUARY 2023		
Tesla Coil driver board	26102221	9.95
Tesla Coil potentiometer board	26102222	5.95
Cooling Fan Controller & Loudspeaker Protector	01102221	8.95
Remote Gate Controller	11009121	12.95
JANUARY 2023		
Classic LED Metronome – 8-LED	23111211	7.95
Classic LED Metronome – 10-LED	23111212	8.95
Multi-Channel Speaker Protector – 6 channel	01101221	9.95
Multi-Channel Speaker Protector – 4 channel	01101222	7.95
Remote Control Range Extender – IR-to-UHF	15109212	5.95
Remote Control Range Extender – UHF-to-IR	15109211	7.95
AO Universal Single Op Amp Board	AO1-JAN23	7.95
DECEMBER 2022		
Hummingbird Amplifier	01111211	9.95
SMD Trainer PCB	29106211A	8.95
SMD Trainer PCB + parts	29106211B	13.95
NOVEMBER 2022		
USB Cable tester – main PCB	04108211	12.95
USB Cable tester – front panel	04108212	5.95
USB Cable tester – optional panel	SC5970	5.95
Model Railway Carriage Lights – PCB	09109211	6.95
AO transfmr PCB – standard VTX-A range	VTX-101-007	6.95
AO transfmr PCB – dual-outline VTX102-3001/101-3002	VTX-Dual	6.95
OCTOBER 2022		
SMD Test Tweezers – PCB and pair of tweezer arms	04106211-2	11.95
SMD Test Tweezers – programmed PIC12F1572-I/SN	0410621A	7.95
Tele-com	12110211	12.95
SEPTEMBER 2022		
Touchscreen Digital Preamp – main board	01103191	12.95
Touchscreen Digital Preamp – adaptor board pair	01103192	5.95
20A DC Motor Speed Controller	11006211	9.95
AUGUST 2022		
Multi-purpose Battery Manager – I/O Expander module	11104212	5.95
Multi-purpose Battery Manager – Switch Module	11104211	8.95
Simple MIDI Music Keyboard (for 8 switches)	23101213	6.95
Nano Pong	08105212	7.95
JULY 2022		
Silicon Labs AM/FM/SW Radio	CSE210301C	10.95
Level Crossing Controller	09108211	6.95
JUNE 2022		
Full-wave Motor Speed Controller	1010221	8.95
PIC Programming Helper for 8-pin PICs only	24106211	7.95
PIC Programming Helper for 8, 14 or 20-pin PICs	24106212	10.95
Advanced GPS Computer	05102211	9.95
MAY 2022		
Bus board PCB for Analogue Vocoder	AO1-MAY22	10.95
Complete set of 14 PCBs for Analogue Vocoder	AO2-MAY22	97.95
Programmed EEPROM for Digital FX Unit	FX1-MAY22	10.95
Programmed PIC for Digital FX Unit using potentiometer	FX2-MAY22	8.95
APRIL 2022		
64-key MIDI Matrix shield	23101211	8.95
64-key MIDI Matrix switch board	23101212	11.95
High-current Battery Balancer	14102211	10.95
Digital FX Unit – using potentiometer	01102211	9.95
Digital FX Unit – using BCD switch	01102212	9.95
Universal Audio PSU	AO1-APR22	11.95
MARCH 2022		
Mini Isolated Serial Link	24102211	£5.95
Busy Loo Indicator	16112201	£5.95
Analogue Vocoder – Band-pass filter board	AO1-MAR22	9.95
Analogue Vocoder – HP/LP filter board	AO2-MAR22	9.95
FEBRUARY 2022		
Arduino-based Power Supply	18106201	9.95
Battery Monitor Logger	11106201	10.95
Electronic Wind Chimes	23011201	10.95
Analogue Vocoder – Driver Amplifier	AO-FEB22	8.95
JANUARY 2022		
Vintage battery Radio Li-ion Power Supply	11111201	9.95
MiniHeart: A Miniature Heartbeat Simulator	01109201	8.95
DECEMBER 2021		
AM/FM/SW Digital Receiver	CSE200902A	13.95
Balanced Input and Attenuator for USB CODEC	01106202	11.95
NOVEMBER 2021		
Dual Battery Lifesaver	11111202	£6.95
OCTOBER 2021		
Mini Wi-Fi LCD BackPack	24106201	£8.95

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

PROJECT	CODE	PRICE
SEPTEMBER 2021		
USB SuperCodec PCB	01106201	£14.95
Audio DDS Oscillator PCB	01110201	£5.95
Audio DDS Oscillator rotary encoder	01110201-ENC	6.95
Programming Adaptor Board for Audio DDS Oscillator	01110202	£5.95
High-power Ultrasonic Cleaner main PCB	04105201	£14.95
High-power Ultrasonic Cleaner front-panel PCB	04105202	
Night Keeper Lighthouse PCB	08110201	£5.95
AUGUST 2021		
Ol' Timer PCB	19104201	£11.95
Ol' Timer 8x8 RGB LED module using WS2812B	19104201-88	£8.95
Ol' Timer set of acrylic case pieces and spacer	19104201-ACR	£8.75
Ol' Timer DS3231 RTC IC wide SOIC-16	19104201-RTC	£5.95
Wideband Digital RF Power Meter	04106201	£9.75
Switchmode 78xx regulators ***(PACK of 5!)***	18105201	£7.95
Cool Beans SMAD display	CB-AUG21	£11.95
JULY 2021		
ATtiny816 Breakout / Dev Board with Capacitive Touch	24110181	£9.75
IR Remote Control Assistant (Jaycar version)	15005201	£8.95
IR Remote Control Assistant (Altronics version)	15005202	£8.95
PIC18F Development Board	PNM-JUL21	£12.95
Microphone Preamplifier	AO-JUL21	£11.95
JUNE 2021		
Roadies' Test Signal Generator (surface-mount version)	01005201	£8.95
Roadies' Test Signal Generator (through-hole version)	01005202	£9.95
Touchscreen Wide-range RCL Box (Resistor module)	04104201	£18.95
Touchscreen Wide-range RCL Box (Ind/Cap module)	04104202	
KickStart Part 3 – Gyrator-based Audio Filter	KS3-2021	£7.95
MAY 2021		
7-Band Equaliser (Mono)	01104201	£8.95
7-Band Equaliser (Stereo)	01104202	£10.95
Car Altimeter	05105201	£7.95
APRIL 2021		
Reflow Oven – DSP Active Crossover (CPU)	01106193	£19.95
Reflow Oven – DSP Active Crossover (Front panel)	01106195	
Reflow Oven – DSP Active Crossover (LCD)	01106196	
Frequency Reference Signal Distributor	CSE200103	£8.95
MARCH 2021		
Nutube Guitar Effects Pedal	01102201	£12.95
Programmable Thermal Regulator (Peltier Interface)	21109181	£18.95
Programmable Thermal Regulator (Peltier Driver)	21109182	
Tunable HF Preamp	CSE190502	£8.95
FEBRUARY 2021		
4G Remote Monitoring	27111191	£9.95
JANUARY 2021		
Nutube Valve Preamplifier	01112191	£12.95
Arduino DCC Controller	09207181	£10.95
DECEMBER 2020		
Pseudo-Random Sequence Generator	16106191	£7.95
Clever Charger	14107191	£11.95
PE Theremin Amplifier	AO-1220-01	£8.95

PROJECT	CODE	PRICE
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OCTOBER 2020		
Digital Audio Millivoltmeter	04108191	£9.95
Precision Signal Amplifier	04107191	£7.95
SEPTEMBER 2020		
PE Theremin PSU	AO-0920-01	£5.95
PE Theremin PSU transformer	AO-0920-02	£7.95
Micromite Explore-28	07108191	£6.95
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AUGUST 2020		
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	18108173	
	18108174	
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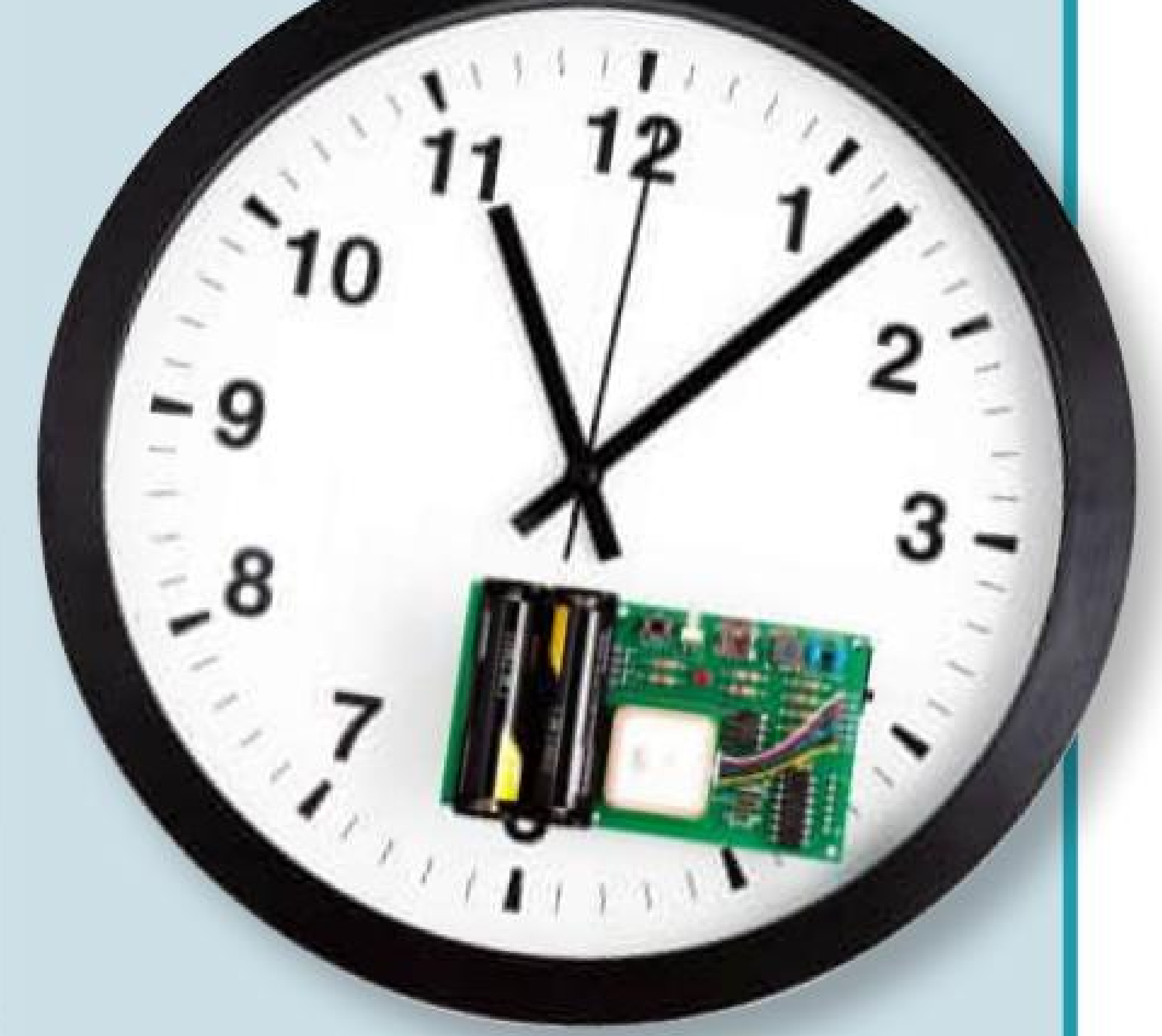
For editorial contact details see page 7.

Next Month – in the September issue

GPS-Synchronised Analog Clock with long battery life

This GPS Clock Driver converts an ordinary wall clock into a highly accurate timepiece that will keep exact time (within seconds) for up to eight years using a pair of C cells. You need not touch the clock during that period; it will automatically adjust for daylight saving by adding and subtracting an hour exactly when needed. This is a clock you can rely on to tell you the correct time.



Mini LED Driver

This small, low-cost module can drive relatively large 12V white LEDs from a USB or 5V DC power source. Sometimes you don't need a floodlight; a modest amount of light is enough, and the Mini LED Driver is an economical way to deliver it.

Wide-Range OhmMeter – Part 2

This Wide Range Ohmmeter is more useful than a milliohm meter. It measures very low resistances, down to around 1mΩ, but it can also measure up to 20MΩ with an accuracy of around ±0.1%. That makes it handy in any electronics lab, and it's easy to use; just connect a device and read off its value. Having described how it works, next month we'll move on to building it.

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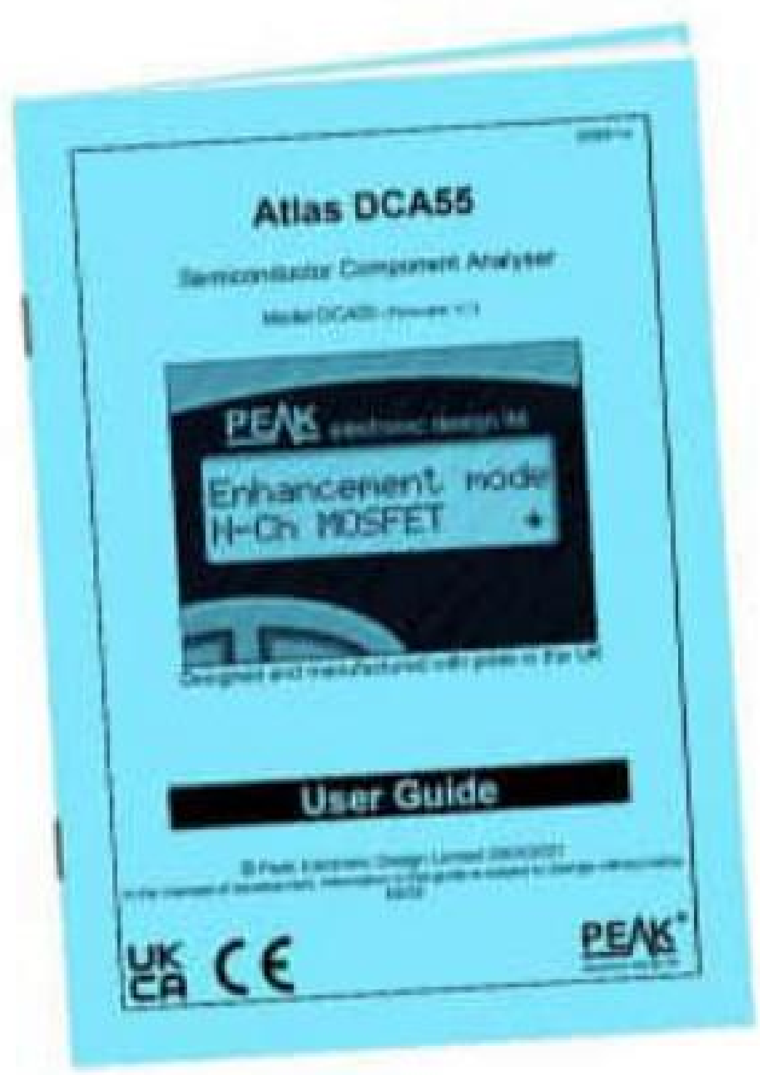

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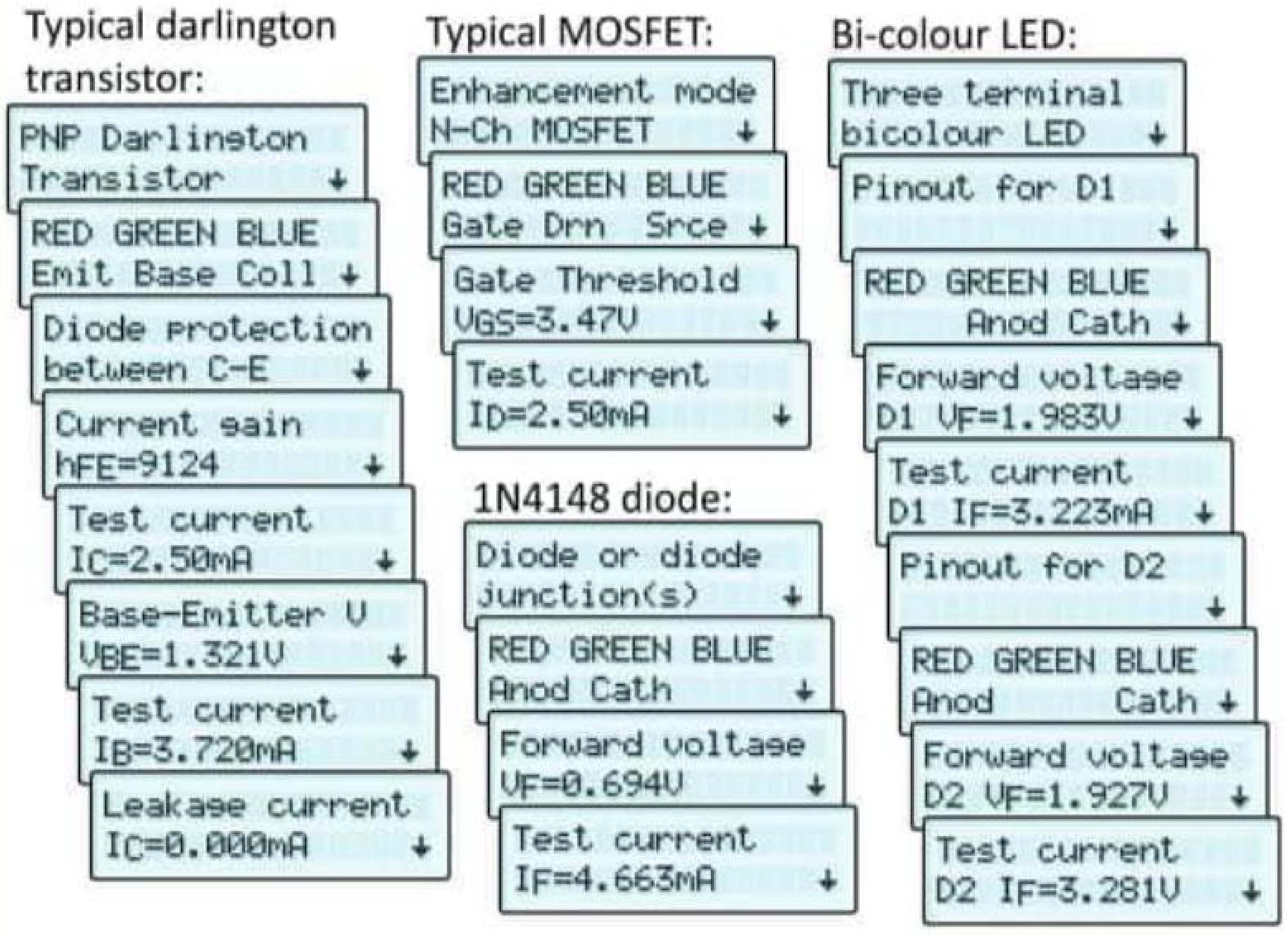

Typical darlington transistor:

```
PNP Darlington
Transistor      ↓
RED GREEN BLUE
Emit Base Coll ↓
Diode protection
between C-E    ↓
Current gain
hFE=9124       ↓
Test current
IC=2.50mA      ↓
Base-Emitter V
VBE=1.321V     ↓
Test current
IB=3.720mA     ↓
Leakage current
IC=0.000mA     ↓
```

Typical MOSFET:

```
Enhancement mode
N-Ch MOSFET    ↓
RED GREEN BLUE
Gate Drn  Srce ↓
Gate Threshold
VGS=3.47V      ↓
Test current
ID=2.50mA      ↓
```

1N4148 diode:

```
Diode or diode
junction(s)    ↓
RED GREEN BLUE
Anod Cath      ↓
Forward voltage
VF=0.694V      ↓
Test current
IF=4.663mA     ↓
```

Bi-colour LED:

```
Three terminal
bicolour LED   ↓
Pinout for D1
               ↓
RED GREEN BLUE
     Anod Cath ↓
Forward voltage
D1 VF=1.983V   ↓
Test current
D1 IF=3.223mA  ↓
Pinout for D2
               ↓
RED GREEN BLUE
Anod      Cath ↓
Forward voltage
D2 VF=1.927V   ↓
Test current
D2 IF=3.281V   ↓
```

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